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AN EFFICIENCY TEST
OF THE STATE CAPITOL PLANT AT MADISON WISCONSIN

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A Thesis Submitted for the Degree of

BACHELOR OF SCIENCE

In the Electrical Engineering Course

AND BY

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A Thesis Submitted for the Degree of

BACHELOR OF SCIENCE

In the Mechanical Engineering Course

UNIVERSITY OF WISCONSIN

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INTRODUCTION

The object of this thesis is the complete testing of the plant recently installed in the State Capitol Building at Madison,Wisconsin. The plant furnishes the heating, lighting and ventilating for the entire building and is also capable of lighting the grounds.

There is but little doubt of the value of frequent tests upon such plants. No matter how well arranged or how carefully managed the best of plants are liable to losses and wastes of power which can only be detected by a rigid and accurate test of the same. These losses,unless checked,are certain to increase with time. It is therefore evident that only by tests conducted at frequent intervals can a plant be held to its best efforts.

It is of especial value to test a plant immediately after its installation. A determination can then be made of:- first,how nearly it realizes the expectations of its builders; and second,the degree of perfection attained by modern practice along these lines.

Such tests as the present have resulted in two things: first they have shown what machinery in the plant is not performing its full duty: and second,as a logical outcome, have caused the manufacturers to improve their products.

As a result of this last,many eminent authorities claim that the modern steam engine is capable of but very little increase in its efficiency. The electrical apparatus, being of more modern development,is still capable of quite an improvement along these lines.

Tests of the nature of the one under consideration must appeal to the non-technical and technical man alike. The persons in charge,and especially those in charge of the actual running of the plant,are very likely to be of the former class. All the essential data and results must be given in as simple and straight-forward a manner as possible and must be capable of easy verification in case of doubt as to their accuracy.

Modern standard methods of testing have approximated very closely the accuracy of the physicist and chemist. The young engineer of today is almost invariably trained in the exact methods of these laboratories and their apparatus is largely used in the making of modern tests. The determination of temperatures and weights,the analysis of fuels,ashes and gases are examples of these facts.

All apparatus used in these tests should be of reliable and accurate make and should have been calibrated previous to the test by some standard method.

The data and results required in the determination of the performance of a plant are obtained by means of simultaneous readings from all the instruments,at regular and

frequent intervals. Taken in this way a substantially continuous record of all apparatus used in the test may be obtained.

DESCRIPTION OF PLANT.

As stated before the plant is designed for heating, lighting and ventilating. The boilers are four in number of 150 H.P. each. They are steel boilers built by the Kewaunee Boiler Co. and are of the "water-tube" type. Each boiler contains 76,four inch tubes,17 feet long,giving a total heating surface of 1493 square feet.

The boilers supply steam to two high speed McEwen engines. One of 150 H.P. directly connected to a 100 K.W. Western Electric generator. The other of 75 H.P. directly connected to a 50 K.W. generator of the same make.

The exhaust steam from the engines is so connected that it may be sent through heating coils and radiators for the purpose of ventilation and heating or it may be exhausted directly to the roof. From these coils the condensed water passes directly to a receiver from which it is pumped to the boilers. Whatever other water may be needed is supplied from the water mains,and passes through a feed water heater before entering the receiver. There are two Fairbanks Morse,6" x 4" x 6" duplex pumps. One only is needed,the other being held as a reserve in case of an emergency.

The motor-compensator three wire system is used in the distribution of power. The voltage across the outside

wires is kept at 234 and from the neutral to the outside at 117. Across the bus bars of the switch-board is a Western Electric compensator of 14 K.W. capacity. (The total number of lamps wired up is 2500, 115 volt, 16 candle power incandescents and 22, 5 ampere, 110 volt inclosed arc lamps.) The power is distributed from the engine room through a marble switch-board equipped with Weston Voltmeters and Ammeters, a Thomson Integrating Watt-hour-meter, Crouse Hinds switches and Western Electric circuit breakers.

The ranges of the instruments are as fòllows;-

Weston	Station	Voltmeter,	Number	4106,	scale	0 - 250
"	"	"	"	3155,	"	0 - 250
"	"	Ammeter	"	4111,	"	0 - 600
"	"	"	"	3039,	"	0 - 300
"	"	"	"	4078,	"	100-0-100
"		"	"	35243,	"	0 - 600
"		"	"	35228,	"	0 - 100
"		"	"	35464,	"	0 - 150
"		"	"	35290,	"	0 - 150

Thomson Integrating Wattmeter, #576272, Amperes 1200, Volts 220, 10,000,000. watt-hours.

From the switch-board the power for lighting is distributed through two large tablets, lettered "A" and "Y". From these it is distributed to 22 different tablets situated at convenient points in the building. From each of these tablets the circuits lead out to the different rooms

and offices.

The power used in veltilating the building is also taken from the main switch-board. There are two fan rooms each containing a 15 H.P.,Western Electric motor,belted to a 10 x 5 ft. fan. These fans draw air through the heating coils and force it into the ducts,and thence to the rooms. The fan motors are so arranged that their armatures may be supplied with either 110 or 220 volts. The fields are,however,always excited from the 220 volt service. This arrangement permits of running the fans at half speed and full speed respectively. The motors are generally started with 110 volts on the armatures and then thrown on the 220 volt service if full speed is desired.

DESCRIPTION OF TEST

The test was made from 2.15 April 24th, until 2.15 April 25th, 1903. The plant was run under normal conditions at all times and no attempt was made to improve its efficiency. The observations and readings were taken by members of the Senior and Junior classes in electrical and mechanical engineering.

Boilers: The coal was weighed as fed to the boilers by means of a Fairbanks Morse scale. Pieces of coal were taken from time to time for the purpose of fuel analysis. Before starting, the ashpits were emptied and the ashes accumulated during the test were weighed.

The water fed to the boilers came from two sources,- the return from the engines and the water mains. The feed-water heater is used for raising the temperature of the water from the mains. Exhaust steam is used in this heater. We found it impossible to break the connections of the heater with the receiver and therefore it was not used during the test. Under ordinary conditions of running, both the return water and that from the mains flow into the receiver. From here it is pumped into the boiler. There is a drain from the receiver into the hot well. This we intercepted and led the water into two barrels. Each barrel was placed upon a scale and so arranged as to empty

into a common tank. The barrel was weighed when full and when empty, the difference giving the amount of water discharged into the tank. The cold water from the mains was fed into a third barrel and discharged into the same tank. The pipe between the receiver and the pump was disconnected and led into this tank. In this way the water was pumped directly from the tank into the boilers. A thermometer placed in the tank gave the temperature of the feed water which was found to vary a good deal according to the amount of cold water used. Readings of feed water temperature and boiler pressure were taken every fifteen minutes.

A throttling calorimeter was placed directly over the boilers and readings taken every 30 minutes. The quality of the steam was thus determined.

Samples of flue gas were taken every hour and tested as regards their contents of CO_2, CO, and O. These tests were made at the plant by means of Orsat's apparatus. The gases were taken from the chimney by means of an iron pipe and two small cans. These cans were connected by means of a rubber tube and one of them was connected in a similar way to the pipe. The can attached to the pipe was filled with water and the pipe inserted in a hole in the chimney. By lowering the empty can the water flows out of the full one and thus draws the gas into it. After the can is full all connections are closed and the gas is ready to be tested.

Orsat's apparatus involves the use of chemicals and is operated as follows. There are three pipettes containing respectively solutions of caustic potash to absorb the carbon dioxide,pyrogallic acid and caustic potash to absorb the oxygen and cuprous chloride in hydrochloric acid to absorb the carbon monoxide. The gas to be tested is first forced into a large tube until the tube contains just 100 cubic centimeters of gas. By noting the number of cubic centimeters absorbed by each,the percentages of the different constituents can be determined. The temperature of the flue gases was taken every hour by means of a pyrometer. The draft in the chimney was also abtained by means of a draft gauge.

Feed Pump: A stroke counter was placed upon the feed water pump and the total number of strokes during the test registered. After the test the exhaust steam from this pump was condensed for a short time and the number of strokes during this interval also noted. The steam used per stroke was thus obtained and hence the amount of steam used by the pump during the test determined.

Engines: At the time of the test the armature of the small generating set was loose on the engine shaft,and we were therefore only able to make a test of the large generating set.

Indicator cards were taken every ten minutes at the head and crank ends of the cylinder. The speed was also

taken every ten minutes by means of a Starret hand speed counter and a stop watch. A throttling calorimeter placed directly over the cylinder gave the quality of the steam. This was taken every half hour.

The losses in the engine and dynamo were determined by running without load and taking indicator cards at the same time.

Switch Board: Readings were taken of all instruments every ten minutes. The two voltmeters gave the total voltage and voltage on each side. There were ammeters for each part of the load (incandescent,arc,dome and the fan motors)and for reading the total current. Thus it was possible to obtain the different divisions of the load. One central zero ammeter also gave the amount of excess current carried by either side of the system.

Tablet Readings: During the test simultaneous readings were taken at the switch-board and at several of the distributing tablets,the object being to determine the drop and whether or not it was excessive. An approximate count was also made of the number of lamps burning.

Fan Motors: One of the fan motors was out of service at the time of the test and hence only one could be tested. The motor conditions proved so constant that only a seven hour run was deemed necessary. Readings were taken of the armature and field currents,and of the impressed voltage and speed. A stray power test of the motor was made after

the regular run. This was conducted as follows. The readings of the current,voltage and speed were averaged. Knowing the armature resistance and average armature current,the CR drop in the armature was calculated. The average impressed pressure minus this CR drop gave the average counter pressure of the motor. This pressure was then impressed on the armature and the field weakened until the motor ran at the same speed as during the regular test. The power supplied to the armature under this condition was then the stray power of the motor.

An attempt was made to measure the output of the fan. The velocity of the air was measured as it came from the fan by means of an anemometer. The air was,however,too swift for the anemometer and after two readings had been taken the instrument broke down.

Additional tests of circuits for grounds,insulation and resistance were made before the regular test of the plant and were for the purpose of determining how nearly the installation met the requirements of the specifications.

As has been previously stated the Edison three wire system is employed in the lighting of the building. From the switch-board the current is carried to the main tablets "A" and "Y". From these two tablets it is carried by means of three wires to the various distributing tablets in different parts of the building. From these it is distributed to the lights over two wires. Tablet "Y"

supplies the dome only.

There are 24 distributing tablets located as follows:-

Basement,	Tablets	B, C, G, F, D, E.
1st Floor,	"	H, I, A.
2nd "	"	M, N, L, O, P, K, Y, J.
3rd "	"	Q.
4th "	"	S, T, R, U.
Dome	"	V, W.

Between the various tablets are run "equalizers" in order that the load may be more readily balanced.

The main circuits leading to each tablet and also the equalizers were tested both for insulation between wires and for grounds. The distributing circuits from the tablets to the lamps were tested only for grounds. This was done by opening the switch for the particular circuit and treating the circuit through the lamps and back to the tablet as one wire. A portable Wheatstone bridge with a capacity of eleven meg-ohms was used during these tests. All tablets with the exception of "J" gave the insulation resistance equalling the capacity of the bridge. Tablet "J" showed a resistance of 50000 ohms.

The resistance of the different circuits was also measured. This was done by short circuiting the switches on tablet "A" and measuring from each tablet to "A". Only a part of the circuits were tested.

The results were as follows:-

From	tablet	"A"	to	tablet	"H",	Res.	0.135	ohms.
"	"	"	"	"	"S"	"	0.155	"
"	"	"	"	"	"R"	"	0.155	"
"	"	"	"	"	"N"	"	0.204	"
"	"	"	"	"	"L"	"	0.115	"
"	"	"	"	"	"Q"	"	0.125	"
"	"	"	"	"	"E"	"	0.140	"
"	"	"	"	"	"B"	"	0.195	"
"	"	"	"switch-board			"	0.002	"
From	tablet	"Y"	to	tablet	"U"	"	0.050	"
"	"	"	"	"	"V"(dome)		0.100	"
"	"	"	"	"	"V"(sky)		0.105	"
"	"	"	"	switch-board			0,015	"

CALCULATION OF DATA

COAL TEST.

In making the coal analysis small amounts were taken from the different samples of coal taken during the test, (which had been kept in sealed jars) and ground to a fine powdered mass. Two,one gram samples of this were taken, one as a check upon the other,and each was tested in the following way for the percentage of moisture,volatile matter and ash. In order to determine the moisture,the samples were first weighed while in small crucibles,the weight of the crucible having been determined before hand. They were then placed in an air bath and kept from one and a half to two hours,at a temperature of 260 degrees F., being weighed occasionally until they no longer lost in weight. This gave the amount of moisture in the sample. The volatile matter was found by heating the crucible in an ordinary gas flame for three minutes and in a forced blast for the same length of time. The loss in weight due to the heating gives the amount of volatile matter. Finally the ash was determined by burning the sample in the crucible to an ash,taking precautions that none was lost in the blast of the flame,and weighing the same. In all of these determinations the weight of the crucible had

of course, to be taken from the weight obtained.

The British Thermal Units in the coal were found by means of the Bomb Calorimeter. This instrument consists of an air tight, steel receptacle in which a certain known weight of dry coal is placed and the chamber is filled with oxygen at a pressure of 25 atmospheres and then closed. This receptacle is then placed in a vessel containing a certain amount of water and which is protected against loss of heat by an outside water-jacket, the whole vessel being covered with felt. The coal and oxygen are then exploded by an electric spark and the exact rise in the temperature of the water is obtained. The B.T.U.s in the coal are then found by referring to a calibration curve of the instrument, giving the actual B.T.U.s present per degree rise of the thermometer.

This method was followed out in the use of the instrument except that oxygen at fifteen atmospheres was used as it was the highest pressure to be obtained at the time the analysis was made.

BOILER.

The B.T.U. in the coal was found by multiplying the B.T.U. per pound of coal, from the fuel analysis, by the pounds of dry coal.

The B.T.U. developed by the boiler are found as follows. Pounds of dry steam evaporated, multiplied by the B.T.U. per pound at the absolute boiler pressure, gives the total B.T.U.

in the dry steam. Pounds of moisture in the steam, multiplied by the B.T.U. per pound at the absolute boiler pressure,gives the total B.T.U. in the moisture of the steam. The sum of these two gives the total B.T.U. delivered by the boiler. The B.T.U. in the feed water is subtracted from this sum and the remainder is the B.T.U. developed by the boiler.

The difference between the B.T.U. in the coal and the B.T.U. developed by the boiler gives the number of B.T.U. lost in the chimney,cinders and by radiation.

The B.T.U. developed by the boiler divided by the B.T.U. in the coal gives the boiler efficiency.

FEED PUMP.

The B.T.U. delivered to the pump were found by multiplying the pounds of dry steam and moisture supplied the pump by their respective values of B.T.U. per pound. The sum of these two values gives the total B.T.U. delivered to the pump.

ENGINE.

The B.T.U.delivered to the engine were calculated in the same manner,using the number of pounds of steam delivered to the engine.

The horse power developed by the engine is found from the indicator cards. The delivered horse power is taken from the switch-board readings. The delivered H.P.

divided by the developed H.P. gives the efficiency of the combined engine and generator.

The losses in the engine and dynamo were separated by means of the no load indicator cards and the manufacturers data on the dynamo.

The B.T.U. converted into work by the engine was found by multiplying the developed H.P. hours by the B.T.U. per H.P. hour.

There was no way of measuring the temperature of the exhaust and it was therefore impossible to determine the thermodynamic efficiency of the engine.

SWITCH BOARD.

In the switch board calculations the product of the different readings of the voltmeters and ammeters gave the watts for the different parts of the load. The reading of the integrating wattmeter also gave the total watts consumed by the entire load. The total watts as read from the wattmeter and the voltmeters and the ammeters were found to differ by a slight amount.

DESCRIPTION OF MACHINERY

LARGE GENERATOR SET.

Engine:- Mc Ewen. No.1024 Manufactured by the Ridgway Dynamo and Engine Co.,Ridgeway,Penn. Rated H.P. 150 Stroke 16" Bore 14"

Generator:- Type L - $5\frac{1}{2}$ - 100 K.W. Manufactured by Western Electric Co.

Special rating 240 volts -0 amperes - 255 R.P.M. no load.
" " 250 " -400 " -250 " full load.

Resistance hot.	0.25 load	0.50 load	0.75 load	Full load	1.25 load
Arm. .02325 ohms C^2R	232	930	2092	3720	5812
Brushes- " "	38	122	237	376	540
Series Coils .0083 ohms C^2R	54	216	486	865	1350
G.S. shunt .0347 " "	13	50	117	206	326
Shunt coils & Rheostat "	1458	1493	1513	1545	1555
Total,	1795	2811	4445	6712	9583
Hysteresis & Eddy Currents	1152	1277	1402	1527	1652
Bearing & air friction	350	350	350	350	350
Brush friction	523	523	523	523	523
Total stray power	1152	1277	1402	1527	1652

	0.25 load	0.50 load	0.75 load	Full load	1.25 load
Total S.P. & C^2R	2947	4088	5847	8239	11235
Output	25000	50000	75000	100000	125000
Energy absorbed	27947	54088	80847	108239	136235
Direct Current Eff.	89.5	92.4	92.8	92.4	91.7

SMALL GENERATOR SET.

Engine:- Mc Ewen,No.1025 Manufactured by Ridgway Dynamo & Engine Co. Rated H.P. 80 Stroke 12" Bore 10"

Generator:- Manufactured by Western Electric Co.

Type L - 4 - 50 K.W.

Special rating 240 volts - 0 amperes - 286 R.P.M. no load.
" " 250 " 200 " - 280 R.P.M. full load.

Resistance Hot	0.25 load	0.50 load	0.75 load	Full load
Arm. .0406 ohms C^2R	102	406	914	1624
Brushes - " "	25	80	150	244
Series coils .01934 ohms C^2R	20	79	175	312
G.S. shunt .0338 " "	11	44	102	180
Shunt coils & rheo. " "	875	892	909	925
Total	1033	1501	2250	3285
Hysteresis & Eddy currents	1086	1164	1241	1319
Brush friction	146	146	146	146
Total stray power	1232	1310	1387	1465
Total S.P. & C^2R	2265	2811	3637	4750
Output	12500	25000	37500	50000
Energy absorbed	14765	27811	41137	54750
Direct current efficiency	84.7	89.8	91.1	91.3

COMPENSATOR.

Manufactured by the Western Electric Co. Type G.M. 14 Nos. 13395 & 13396 Speed 1450 R.P.M. Volts 115 - 125

Capacity unbalance = 14 K. W.

FAN MOTORS.

Manufactured by the Western Electric Co. Type R.G.I. Nos. 14407 & 15006 Amperes 55 Volts 240 H.P. 15 R.P.M. 875

FEED WATER HEATER.

Webster Vacuum Feed Water Heater and Purifier. Mnfg. by Warren Webster & Co. Camden, N.J. Capacity for 250 H.P.

RESULTS

FUEL.
Number of pounds of coal burned - - - - - - - - - - - 8,196.
" " " " ash - - - - - - - - - - - - - - - - 1,014.
" " " " dry coal (computed) - - - - - 7,991.
Percentage of moisture in coal - - - - - - - - - - - 2.5
" " ash " " - - - - - - - - - - - 2.4
" " volatile matter in coal - - - - - - - -
B.T.U. per pound of dry coal - - - - - - - - - - - - - 15080.
Total B. T. U. in coal - - - - - - - - - - - - - - 120,484,280.

BOILER.
Pounds of water evaporated - - - - - - - - - - - - - 72,098.
Temperature of feed water - - - - - - - - - - - - - - 154.
B. T. U. in feed water - - - - - - - - - - - - - 8,817,585.
Average pressure of boiler by gauge - - - - - - - 75.4
Barometer pressure - - - - - - - - - - - - - - - - - - 14.4
Average pressure of boiler (absolute) - - - - - - - 89.8
Percentage of moisture in steam at boiler - - - - 1.09
Pounds of dry steam delivered by boilers - - - - 71,300.
Pounds of moisture delivered by boilers - - - - - 798.
B. T. U. per pound of dry steam - - - - - - - - - 1,179.54
Total B. T. U. in dry steam - - - - - - - - - - - 84,098,350.
B. T. U. per pound of moisture - - - - - - - - - 289.84
Total B. T. U. in moisture - - - - - - - - - - - - 230,260.
Total B. T. U. delivered by boilers - - - - - - 84,328,610.
Total B. T. U. developed by boilers - - - - - - 75,511,025.
B. T. U. lost in chimney and radiation - - - 44,973,265.
Efficiency of boiler - - - - - - - - - - - - - - - - 62.7%

PUMP.
Number of strokes - 10,098.
Steam used per stroke - - -(pounds) - - - - - - - - 0.145
Total steam used - 1,464.
Dry steam used - 1,448.
Moisture in steam - - - - - - - - - - - - - - - - - - - 16.
B. T. U. in dry steam (total) - - - - - - - - - - -1,707,916.
B. T. U. in moisture (total) - - - - - - - - - - - - 4,637.
B. T. U. used by pump - - - - - - - - - - - - - - 1,712,553.

ENGINES.
Pounds of steam used - - - - - - - - - - - - - - - - 68,634.
Average absolute pressure - - - - - - - - - - - - - 89.8
Average I. H. P. - - - - - - - - - - - - - - - - - - 60.7
Total H. P. hours - - - - - - - - - - - - - - - - - - - 1,457.

Engines.(continued.)

Steam used per H.P. per hour	47.1
Moisture in steam (percent)	1.85
Pounds of dry steam used by engine	66,364.
Pounds of moisture used by engine	1,270.
B. T. U. per pound of dry steam	1,179.5
B.T.U. per pound of moisture	289.8
Total B.T.U. in dry steam	78,276,338.
Total B.T.U. in moisture	368,046.
Total B.T.U. delivered to engine	78,644,384.

SWITCHBOARD.

Average voltage	234.84
Average total current	170.2
Total watts (voltmeter-ammeter reading)	39,935.7
Average horse power	53.5
Total horse power hours (A - V readings)	1,284.7
Total watt-hours (wattmeter readings)	965,000.
Horse power hours " "	1,293.6
Average horse power " "	53.9
Average current - main light circuit	87.04
Average horse power " " "	27.37
Horse power hours " " "	658.88
Average current - dome circuit	68.
Average horse power " "	21.43
Horse power hours " "	39.29
Average current - motors	67.41
Average horse power - motors	21.19
Horse power hours "	508.77
Compensator losses,average current	10.23
" " " horse power	3.24
" " " horse power hours	77.76

Switchboard B. T. U.

Total	3,269,561.
Main light circuit	1,676,900.
Dome circuit	99,993.
Motor circuit	1,294,820.
Compensator and switchboard losses	197,848.

EFFICIENCIES

Efficiency test of engine.

Horse power of engine and dynamo running light	5.15
H.P. lost in generator friction and brush friction from the manufacturers data	1.17
H.P. lost in hysteresis and Eddy currents from the manufacturers data	1.61
H. P. lost in dynamo	2.78
H. P. lost in engine	2.37
Indicated horse power	60.7
Delivered horse power	58.4
Efficiency	95.2%

Efficiency test of motor.

Average speed during test of plant	832.4
Average impressed pressure	229.2
Average current - armature	67.7
Average field current	1.24
Resistance of armature - ohms	0.193
Resistance of fiels - ohms	168.15
Average stray power losses (test) watts	745.0
Average armature C^2R loss,-watts	886.0
Average field C^2R loss - watts	260.0
Total losses - watts	1,891.
Total average input of motor - watts	15,784.
Total average output of motor - watts	13,893.
Efficiency	89.03%

Boiler	62.7%
Engine to switch-board (voltammeter readings)	88.09%
Engine to switch-board (wattmeter readings)	88.68%
Dynamo (manufacturers data)	91.4%
Engine (from electrical data)	96.32%
Engine from no load indicator cards	95.2%
Motor stray power test	89.03%
Coal to engine	65.2%
Coal to dynamo	3.08%
Coal to switch-board	2.71%

SUMMARY BRITISH THERMAL UNITS

Contained in fuel	120,484,280.
Contained in feed water	8,817,575.
Boiler develops	75,511,025.
Lost in chimney and radiation	44,973,265.
Delivered to engine	78,644,384.
Delivered to feed pump	1,712,553.
Lost in radiation	3,971,663.
Converted into work by engine	3,711,883.
Delivered to switch-board	3,269,561.
Taken by friction and losses	442,322.
Delivered to incandescent lamps	1,676,900.
" " dome	99,993.
" " fan motor	1,294,820.
" " compensator and switch-board	197,848.

COST OF POWER

In the usual power stations where the power is generated by steam engines,no use is made of the exhaust steam. As is well known the greater part of the power delivered to the engines is lost in the exhaust. * If this steam can be used to advantage the cost of power will be materially reduced. The plant under consideration is therefore able to generate power during those months when the exhaust steam can be used for heating,at a remarkably cheap rate. It will be assumed that this condition will exist during six months of the year. During the colder months the expense of running the plant will be much increased due to the amount of coal necessary to generate the live steam for heating purposes. This extra expense would however be directly chargeable to heating and would not increase the cost of lighting power. While more expense will also be chargeable to electrical power the rate per K.W. hour will be the same,provided the exhaust steam may be used.

Proceeding on this general assumption the following data has been obtained. There are 78,644,000. B.T.U. delivered to the engines of which 3712000 are converted into work. If we assume that 1,288,000. B.T.U. are lost in the cylinders of the engines,this gives 5,000,000.B.T.U.

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*See heat diagram.

chargeable to electrical power, leaving 73,644,000.B.T.U. delivered to the exhaust. The exhaust delivers to the receiver 8,818,000. B.T.U. This leaves 64,726,000.B.T.U. chargeable to the exhaust and 69,726,000. useful B.T.U. The proportion that should be charged to electrical work is $\frac{5}{70}$ or 7.1% . This is during the six months when the exhaust steam may be used. During the other six months the total cost of operation must be charged to electrical power.

During the test of the plant 958 K.W. hours were generated. The cost is as follows:

One chief engineer - - - - - - - $	100.00	per	month.
One assistant engineer - - - -	90.00	"	"
" " "	80.00	"	"
Three firemen - - - - - - - - - -	195.00	"	"
Total - -	$465.00	"	"

Which amounts to $15.50 per day.

8,196. pounds of coal were used at $9.50 per ton, which is $39.13 per day. What little cold water is used,is supplied from the University pump house and is very cheap. Therefore $17.00 per day will be assumed to cover the labor,water,and oil expenses. This makes the total cost of operation at the time of the test, $56.13 per day.

In addition to this the interest on the capital necessary to install the plant and a certain amount of charge for deterioration must be taken into consideration. These are assumed to amount to 11% and 5.5% is that

chargeable to electric power. The cost of the plant was $60,000. which at 5.5% means $3,300. per year, or $9.00 per day. The actual cost of operation, as stated before, is $56.13 per day, of which the 7.1% chargeable to electric power is $ 3.98 This makes the total cost of generating 958 K.W. hours $12.98 which amounts to 1.36 ¢ per K.W. hour. During the six months when the exhaust steam can not be used the total operating expenses must be charged to the electric power, which means that 958 K.W. hours cost $56.13 plus $9.00 or $65.13, which is 6.8¢ per K.W. hour. Taking the average of these two for the average of the year gives 3.97 ¢per K.W. hour.

It was impossible to obtain from the Madison Gas & Electric Co. their prices on this amount of power. From estimates from other sources it is not probable that it could be obtained under 6 ¢ per K.W. hour. The generation of power at 3.97 ¢ per K.W. hour therefore means a saving of at least 33% . The test of the plant was made during April and since the legislature was in session it seems fair to assume the lighting load to be an approximate average for the year.

Assuming power furnished at 6 ¢ per K.W. hour the 548 K.W. hours used for lighting would cost the state per year $12,000. The cost at present is $8,000. By the installation of this plant the state thus saves $4,000. per year as compared with the buying of their power.

Turning to the actual cost of lighting before the installation of this plant a saving is also found. The building was previously lighted by gas. There were 1300 gas jets as against 2,500. incandescent and 22 arc lights at the present time. The cost of lighting by gas, taken from the gas bills for three summer and three winter months during 1902 was $23.53 per day. The cost at the present time is $21.80 per day. The gas lighting cost the state $8,588. per year,while the electric lighting by this plant costs $8,000.,a saving of $588. When the difference in quantity and quality of light under these two systems is taken into consideration this saving in cost and improvement of the service is remarkable.

The cost of operating one motor at full speed for one day is $16.40 During this time the motor supplied 114,048,000. cubic feet of air. The cost per cubic yard was therefore 0.00039 ¢.

As before stated,it is the intention to light the Capitol Park from this plant by means of 24,- 110 volt,- 5 ampere inclosed arcs. At the present time the state is paying $48.00 per month for six arc lights. The lights are turned off at 12 o'clock and hence an assumption of 5 hours per night is about the average time used,therefore, the cost of the 24 lights per month of 30 days will be $78.25 The cost of the installation would be $3,200. allowing 8% for deterioration and interest,this amounts to

$21.50 per month. Hence the total cost would be $99.70 while the same power furnished by the Electric Light Co. would cost $192.00 The present power, of six lights, could be furnished by the plant at $19.50 per month. The interest and deterioration on six lights would amount to $5.40 making the total, chargeable to six lights, $24.90 per month. The result of the state lighting the park will be a saving of $277. per year with six lights, and of $1,100. with 24 lights.

CONCLUSIONS

FUEL.

The coal used by this plant was Pennsylvania anthracite, which appears to be of very high quality,containing a very low percent of moisture and ash and 15,080. B. T. U. per pound of dry coal,which is somewhat above the average.

BOILERS.

The efficiency of the boilers is 62.7% which for this type of boiler seems rather low. The efficiency would be materially increased by working the boilers nearer to their capacity. The quality of steam delivered was practically 100% throughout the test.

ENGINES AND GENERATORS.

It was impossible to calculate the thermodynamic efficiency of the engines due to the fact that the temperature of the exhaust steam as it came from the engine could not be measured.

The generator efficiency (full load) from manufacturers data is 91.4% which is very reasonable. This leaves the engine efficiency from the electrical data 96.32% which is somewhat higher than the efficiency obtained from the no load indicator cards,which was 95.2% The efficiency from engine to switch-board was 88.16% which is extremely high considering the low average load. The efficiency

obtained from one set of simultaneous readings taken at maximum load was 95.6% The same for minimum load was 81.6%

From plate III is seen that the employment of the small engine alone from about 11.30 P.M. to 4.30 P.M. would be an economical method since the small engine has only one half the capacity of the large one and would be worked nearer full load with a correspondingly higher efficiency. The large engine could be run alone for the remaining time providing that the total current does not exceed 400 amperes, which,at 250 volts is the full capacity of the machine. In case the load exceeds this limit the small engine could be started.

The same might be said of the boilers; running only one boiler during the time the small engine is running alone and throwing in the other during the heavy load from 4.30 P.M. to 11.30 P.M. In case considerable live steam is used for heating purposes two or three boilers would have to be run continually.

MOTORS.

The efficiency of the motors obtained by the stray power method was 81.9% which is about the average for this type of machine.

The ability to reduce the voltage across the armatures of the motors from 234 to 117,thereby reducing the speed one half,is a very good idea,as it enables the motors to be

run efficiently at either full or half speed depending upon the desired amount of air required for ventilation.

COMPENSATOR.

The three wire motor-compensator system used appears to work very well,showing that the lamps throughout the building are very judiciously distributed. The average indications of the balancing ampermeter in the neutral wire were about 16 - 20 amperes toward the left,showing that the lamps are about as evenly distributed as is possible under working conditions.

The power consumed by the compensator was 6.03% of the total delivered by the engine. This value was determined from the B.T.U. consumed by the different parts of the plant. The percentage of power would be considerably decreased by working the plant at heavier load.

The necessity of installing another compensator is very evident,the operation of the entire lighting plant depending almost altogether on the operation of the one compensator now employed. In the case of the engines or boilers,if one is disabled sufficient power can be supplied by the other while the first is undergoing repairs (as was the case with the engines at the time that the test was made) But in case the compensator is disabled the whole system, with the exception of the motors which could be run on 220 volts,would have to be shut down until the machine was repaired. The interest on the cost of the extra machine,

$34.00 per year, would be small compared with the inconvenience resulting from such an accident.

The B.T.U. delivered at the switch-board in percent of the total B.T.U. in the coal seemed to be a little low, due to the low boiler efficiency, the cause of this low efficiency having been stated before.

WIRING.

The results obtained from the tests of wiring in the building were very satisfactory both for insulation and comparative resistance of the different circuits taking into consideration the different lengths. The small drop in voltage at the distributing tablets farthest from the generator, when the plant was in operation, points to the fact that these increased distances had been carefully considered in determining the wiring to be installed.

The distributing tablets might possibly have been placed nearer their centers of distribution in one or two cases, though the various problems that presented themselves on installing the wiring may have prevented a better arrangement.

One thing that must always be kept in mind in regard to this plant, its arrangement, operation, etc., is that it is installed in an old building in which no provision had been made for a plant of this kind. Existing conditions had

to be met and general plans for installation made to conform to them. Considering this latter fact the operation and service rendered may be considered satisfactory.

TABLE I.

Time	R.P.M.	I.H.P.	Watt hrs.	Total Current.	Volts.	Elect. H.P.	Eff.
2.15	236	43.5	0	106	238	33.8	77.7
2.25	240	41.6	5000	107	238	34.1	81.9
2.35	241	42.8	5000	106	235	33.4	78.0
2.45	240	42.2	4000	108	235	34.1	80.9
2.55	240	42.9	3000	108	235	34.1	79.5
3.05	240	41.6	6000	109	235	33.4	82.7
3.15	238	43.1	3000	112	235	35.3	81.9
3.25	238	42.7	6000	112	233	35.0	82.0
3.35	233	47.0	3000	135	240	43.4	92.2
3.45	238	53.0	8000	156	235	49.2	92.8
3.55	238	61.2	6000	168	234	52.7	86.0
4.05	238	63.3	6000	187	235	59.0	93.1
4.15	238	69.6	10000	197	232	61.3	88.1
4.25	239	70.7	8000	203	235	64.0	90.5
4.35	241	74.2	7000	207	236	65.5	88.3
4.45	240	76.5	8000	217	235	68.4	89.3
4.55	240	74.9	9000	226	235	71.2	95.0
5.05	240	76.6	8000	221	235	69.6	90.8
5.15	240	113.0	12000	330	236	104.5	92.5
5.25	242	113.3	13000	338	236	107.0	94.2
5.35	240	98.9	13000	302	234	94.7	95.7
5.45	239	97.2	11000	295	235	93.0	95.7
5.55	240	96.4	11000	284	235	92.6	95.7
6.05	241	96.7	11000	284	236	89.7	92.8

TABLE I. (continued)

Time	R. P. M.	I. H. P.	Watt hrs.	Total Current.	Volts.	Elect. H. P.	Eff.
6.15	238	94.2	11000	282	235	92.0	97.8
6.25	239	94.6	12000	278	235	91.7	96.8
6.35	240	95.1	10000	280	236	88.5	93.0
6.45	241	95.8	11000	286	236	90.4	94.3
6.55	240	97.4	10000	297	235	93.6	96.1
7.05	240	110.5	15000	330	235	104.0	94.1
7.15	240	111.6	10000	331	235	104.2	93.5
7.25	240	108.6	15000	328	235	103.3	95.0
7.35	241	114.0	12000	340	235	104.1	91.5
7.45	241	114.6	13000	337	236	106.8	93.1
7.55	240	114.3	12000	340	235	107.1	93.7
8.05	241	114.3	13000	335	236	106.0	92.7
8.15	242	134.9	13000	405	232	126.0	93.5
8.25	242	139.2	13000	414	236	131.0	94.0
8.35	239	136.2	15000	413	236	130.8	96.0
8.45	241	136.9	15000	414	236	131.0	95.8
8.55	242	133.5	16000	410	236	129.9	97.3
9.05	236	121.5	14000	370	235	116.5	95.8
9.15	243	128.2	15000	387	235	122.0	95.1
9.25	238	124.0	12000	370	235	116.5	94.0
9.35	242	132.3	17000	395	235	124.5	93.9
9.45	249	128.6	13000	394	236	124.3	96.6
9.55	242	129.8	18000	390	235	123.0	94.9
10.05	245	129.3	13000	387	235	122.0	94.3

TABLE I.(continued.)

Time	R.P.M.	I.H.P.	Watt hrs.	Total Current.	Volts.	Elect. H.P.	Eff.
10.15	242	108.7	18000	312	236	98.6	90.7
10.25	241	96.1	9000	277	235	89.3	90.5
10.35	238	88.6	11000	268	234	84.0	94.8
10.45	240	89.9	10000	265	234	83.0	92.3
10.55	241	77.0	10000	230	235	72.5	94.1
11.05	240	74.6	9000	220	234	69.0	92.5
11.15	240	44.1	6000	122	234	37.3	84.5
11.25	234	43.7	4500	128	234	40.2	92.0
11.35	240	43.4	4500	128	234	40.2	92.5
11.45	240	42.9	6000	118	234	37.0	86.2
11.55	240	44.0					
12.05	235	41.7	9000	115	226	36.4	87.2
12.15	235	42.4	5000	111	225	35.0	82.4
12.25	238	42.8	6000	110	235	34.7	81.2
12.35	240	41.3	2000	110	234	34.5	83.4
12.45	240	42.4	4000	112	234	35.1	82.8
12.55	240	42.7	4500	112	235	35.3	86.9
1.05	240	41.6	4500	112	235	35.3	84.9
1.15	238	41.7	5000	110	236	34.8	83.5
1.25	235	39.4	4000	113	237	35.8	90.9
1.35	238	41.9	6000	111	234	34.8	83.0
1.45	240	43.0	3000	110	232	34.3	79.8
1.55	235	40.6	3000	112	232	34.8	85.8
2.05	235	41.5	6000	112	232	35.0	84.3

TABLE I. (continued.)

Time	R.P.M.	I.H.P.	Watt hrs.	Total Current.	Volts.	Elect. H.P.	Eff.
2.15	235	39.1	4000	111	233	34.7	88.8
2.25	240	41.8	4000	110	232	34.3	82.0
2.35	240	42.8	5000	110	234	34.5	82.0
2.45	235	39.4	5000	110	232	34.3	87.1
2.55	235	41.6	4000	110	234	34.5	83.0
3.05	235	41.9	5000	110	234	34.5	82.3
3.15	238	42.3	4000	110	234	34.5	81.4
3.25	238	42.1	6000	112	234	35.1	83.3
3.35	240	42.9	5000	113	236	35.7	83.2
3.45	240	42.5	2000	112	236	35.4	83.3
3.55	240	40.9	5000	110	234	34.5	84.3
4.05	240	40.8	4000	110	234	34.5	84.2
4.15	240	41.1	5000	110	234	34.5	83.8
4.25	240	40.7	4000	109	230	33.9	83.3
4.35	238	41.9	5000	112	234	35.1	83.8
4.45	240	42.5	4000	110	232	34.3	80.7
4.55	240	40.8	4000	112	233	35.0	86.0
5.05	238	41.9	4000	111	232	34.7	83.3
5.15	240	42.7	4500	112	232	35.0	82.0
5.25	240	41.4	4500	110	232	34.3	82.9
5.35	240	43.0	4500	110	234	34.5	80.3
5.45	238	41.6	4500	110	232	34.3	82.4
5.55	240	41.8	4500	111	232	34.5	82.4
6.05	241	43.5	4500	112	234	35.1	82.6

TABLE I. (continued.)

Time	R.P.M.	I.H.P.	Watt hrs.	Total Current.	Volts.	Elect. H.P.	Eff.
6.15	241	43.8	4500	112	234	35.2	82.1
6.25	242	42.5	5000	113	235	35.6	83.8
6.35	240	44.3	4000	112	234	35.2	79.4
6.45	241	42.7	5500	111	235	35.0	82.0
6.55	239	43.7	4500	111	235	35.0	80.2
7.05	241	39.4	5000	99	234	31.0	78.7
7.15	240	40.4	3500	100	235	31.5	78.0
7.25	239	42.7	5000	101	235	31.9	74.9
7.35	241	40.7	4500	102	235	32.2	77.3
7.45	241	39.8	2000	102	236	32.3	81.1
7.55	241	38.0	6000	99	234	31.0	81.6
8.05	241	39.4	4500	101	234	31.7	80.4
8.15	242	40.5	4500	101	234	31.7	78.3
8.25	237	40.2	4000	103	234	32.3	80.5
8.35	238	40.8	5000	103	235	32.5	79.8
8.45	240	43.4	3500	104	235	32.8	75.6
8.55	241	42.0	4000	105	234	32.9	78.3
9.05	239	41.4	4000	104	234	32.6	78.7
9.15	236	40.6	4500	105	234	32.9	81.0
9.25	241	42.5	4500	105.5	234	33.1	77.9
9.35	240	41.5	4000	106	234	33.2	80.0
9.45	240	42.2	4500	107	234	33.6	79.8
9.55	239	39.2	5000	107	235	33.7	86.0
10.05	242	43.2	5000	107.5	236	34.0	78.8

TABLE I. (continued.)

Time	R.P.M.	I.H.P.	Watt hrs.	Total Current.	Volts.	Elect. H.P.	Eff.
10.15	240	42.6	5500	107	234	33.6	78.9
10.25	240	42.5	3000	106	235	33.4	78.6
10.35	241	42.6	5000	105	235	33.1	77.7
10.45	240	41.3	3400	106	234	33.2	80.3
10.55	241	44.6	5000	106	235	33.4	74.9
11.05	242	42.1	4000	106	235	33.4	79.3
11.15	242	42.0	4500	106	235	33.4	79.5
11.25	239	41.8	4500	106	235	33.4	79.9
11.35	241	42.5	5000	106	235	33.4	78.7
11.45	242	43.7	3500	106	235	33.4	77.5
11.55	240	42.2	4000	105.5	234	33.1	78.5
12.05	239	40.7	5000	104	235	32.8	80.8
12.15	239	40.8	3500	105	236	33.2	81.4
12.25	239	39.8	5000	102	235	32.2	80.9
12.35	240	41.2	4000	102	235	32.2	78.2
12.45	239	39.5	4000	103	234	32.5	82.0
12.55	240	40.5	4500	102	234	32.0	79.0
1.05	239	41.3	3500	104	235	32.8	79.4
1.15	238	39.1	4500	103	235	32.5	83.1
1.25	236	39.0	4500	101	235	31.9	81.8
1.35	238	39.9	3000	101	235	31.9	79.9
1.45	241	43.4	4000	106	235	33.4	76.9
1.55	238	40.7	4000	105	234	32.9	81.0

TABLE I. (concluded.)

Time	R.P.M.	I.H.P.	Watt hrs.	Total Current.	Volts.	Elect. H.P.	Eff.
2.05	240	41.2	5500	107	234	33.7	82.0
2.15	245	65.7	5000	179	235	56.4	85.2
		60.7	4208	170.2	234.6		88.09

TABLE II.

Amperes.

Time.	Total.	Lamps.	Balancing. Right.	 Left.	Dome.	Motors.
2.15	106	30.5	4			66.0
2.25	107	32.0	4			65.5
2.35	106	33.5	4			65.5
2.45	108	34.5	2			65.0
2.55	108	32.5	3			66.5
3.05	109	33.5	3			68.0
3.15	112	36.0	9.5			66.0
3.25	112	36.0	9.5			67.5
3.35	135	65.5		16		67.0
3.45	156	81.0		19		67.5
3.55	168	92.5		37		67.5
4.05	187	114.0		50		67.0
4.15	197	123.0		60		66.5
4.25	203	127.5		51		67.0
4.35	207	132.5		51		67.5
4.45	217	142.0		54		67.5
4.55	226	149.0		54		67.0
5.05	221	145.0		48		67.0
5.15	330	256.0		25		67.5
5.25	338	249.0		9		67.5
5.35	302	229.0	4.0			67.5
5.45	295	218.0		4		68.0
5.55	284	211.0		2		67.5

TABLE II. (continued.)

Amperes.

Time.	Total.	Lamps.	Balancing. Right.	 Left.	Dome.	Motors.
6.05	284	210		2		67.5
6.15	282	208	4			66.5
6.25	278	200		6		67.5
6.35	280	205.5		7		67.0
6.45	286	211.5		17		67.0
6.55	297	225.5	5			67.5
7.05	330	258.5		8		66.0
7.15	331	258.5		15		67.5
7.25	328	257.5		18		66.5
7.35	340	266.0		14		66.5
7.45	337	265.0		12		67.0
7.55	340	268.0		12		68.0
8.05	335	264.0		3		66.0
8.15	405	262.5		2	69.0	67.0
8.25	414	266.0	11		69.0	67.5
8.35	413	264.0	6		69.0	67.5
8.45	414	260.5			69.5	67.5
8.55	410	260.0	2		69.0	67.5
9.05	370	242.5	18		68.0	67.0
9.15	387	240.0	22		68.5	66.0
9.25	370	245.0	8		68.0	66.0
9.35	395	247.5	18		68.5	66.0
9.45	394	247.5	18		69.5	66.0

TABLE II. (continued.)

Amperes.

Time.	Total.	Lamps.	Balancing. Right.	Balancing. Left.	Dome.	Motors.
9.55	390	243.0	12		69.5	66.0
10.05	387	242.0	9		68.5	66.0
10.15	312	226.5		18		66.0
10.25	277	205.0		10		66.0
10.35	268	194.5		1		66.
10.45	265	191.5		8		67.
10.55	230	153.0		7		67.
11.05	220	96.0		6		67.
11.15	122	46.0		7		67.
11.25	128	43.5		11		67.
11.35	128	44.0		12		67.
11.45	118	42.5		12		67.
11.55						
12.05	115	35.0		16		67.
12.15	111	35.0		16		67.
12.25	110	35.0		16		67.
12.35	110	36.0		16		67.
12.45	112	35.5		16		67.
12.55	112	36.0		16		68.
1.05	112	36.0		16		68.
1.15	110	36.5		16		66.5
1.25	113	36.5		16		67.
1.35	111	36.5		16		67.

TABLE II. (continued.)

Amperes.

Time.	Total.	Lamps.	Balancing.		Dome.	Motors.
			Right.	Left.		
1.45	110	36.5		16		67
1.55	112	36.5		16		67
2.05	112	34.5		16		67.5
2.15	111	34.5		16		67.5
2.25	110	35.0		16		67.5
2.35	110	35.0		18		65
2.45	110	35.0		18		64.5
2.55	110	35.0		18		65
3.05	110	35.0		18		66.5
3.15	110	35.0		18		65.5
3.25	112	35.0		18		66.
3.35	113	35.0		18		66
3.45	112	35.0		18		67
3.55	110	34.0		16		66
4.05	110	34.5		16		65.5
4.15	110	34.0		16		67.
4.25	110	33.5		16		65.5
4.35	112	34.0		16		65.5
4.45	110	34.0		16		67
4.55	112	34.0		16		67.5
5.05	111	34.0		15		67
5.15	112	34.0		16		67
5.25	110	32.0		15		67

TABLE II. (continued.)

Amperes.

Time.	Total.	Lamps.	Balancing.		Dome.	Motors.
			Right.	Left.		
5.35	110	32.0		15		67
5.45	110	32.0		16		66.5
5.55	111	33.0		16		68
6.05	112	32.5		16		68.5
6.15	112	33.0		16		69
6.25	113	33.0		16		68.5
6.35	112	33.5		16		69.
6.45	111	31.0		13		69
6.55	111	28.5		12		69
7.05	99	19.5		12		68
7.15	100	21.0		15		69.5
7.25	101	21.5		15		69.5
7.35	102	22.5		15		69.5
7.45	102	22.0		15		68
7.55	99	19.5		11		69
8.05	101	19.5		11		70
8.15	101	20.0		10		70.5
8.25	103	21.0		9		70.5
8.35	103	21.0		9		70
8.45	104	24.0		10		69
8.55	105	24.5		10		69
9.05	104	26.0		6		67
9.15	105	27.5		7		67.5

TABLE II. (continued.)

Amperes.

Time.	Total.	Lamps.	Balancing.		Dome.	Motors.
			Right.	Left.		
9.25	106	27.5		6.5		68
9.35	106	26.5		6.5		68
9.45	107	28.5		7		68
9.55	107	28.5		6		69.5
10.05	107	29.0		6		69.5
10.15	107	28.5		6.5		68.5
10.25	106	27.5		8		67.5
10.35	105	28.0		8.4		67
10.45	106	28.5		8.5		66.5
10.55	106	29.0		9.4		68
11.05	106	28.5		9.4		67
11.15	106	29.0		9.6		68
11.25	106	29.0		9.5		67.5
11.35	106	29.0		9.5		68
11.45	106	28.5		9.5		67.5
11.55	105	28.5		9.6		67.5
12.05	104	25.5		7		67.5
12.15	105	26.5		6.5		67.5
12.25	102	24.5		8.7		68
12.35	102	25.0		6.5		67
12.45	103	25.0		6.5		67.5
12.55	102	25.0		6.5		68
1.05	104	25.0		6.5		68
1.15	103	25.0		6.5		67

TABLE II. (concluded.)

Amperes.

Time.	Total.	Lamps.	Balancing.		Dome.	Motors.
			Right.	Left.		
1.25	101	25.0		6.5		
1.35	101	25.0		6		66.5
1.45	106	29.0	15			67
1.55	105	27.0	0			67.5
2.05	107	28.0		2.5		67.5
2.15	179	27.0		6	67.5	65

INDEX TO FIGURES AND PLATES

Figure I, Plan of boiler room.
" II, " " engine room.
" III, arrangement of switch-board instruments.
" IV, switch-board connections.
" V, compensator connections.

Plate I, B.T.U. distributed from coal to lamps and motors.
" II, "A"- H.P. from engine to circuits at heaviest load.
"B"- H.P. from engine to circuits at lightest load.
"C"- Total B.T.U. from engine to circuits.
Plate III, "A","B","C","D", shows indicated H.P.,delivered H. P. and efficiency.
"A" - - 2.15 P.M. Friday to 8.55 P.M. Friday.
"B" - - 8.55 P.M. Friday to 3.55 A.M. Saturday.
"C" - - 3.55 A.M. Saturday to 10.15 A.M. Saturday.
"D" - -10.15 A.M. Saturday to 2.15 P.M. Saturday.
Plate IV, ... "A","B","C","D",shows total amperes and amperes in the several circuits. "A","B","C","D",each represent the same time as in plate III.
Plate V, ..."A","B","C","D", show the amperes in the neutral wire. "A","B","C","D", each represent the same time as in plate III.
Plate IV,..."A","B","C", show boiler pressure.
"A"... 2.15 P.M. Friday to 12.15 A.M. Saturday.

"B" ...12.15 A.M. Saturday to 10.15 A.M. Saturday.

"C" ...10.15 A.M. Saturday to 2.15 P.M. Saturday.

Plate VII,...Calibration curve of Weston ammeter No. 5750.

Plate VIII,..Calibration curve of Weston ammeter No. 6258.

Plate IX,.. Calibration curve of Weston voltmeter No. 4450.

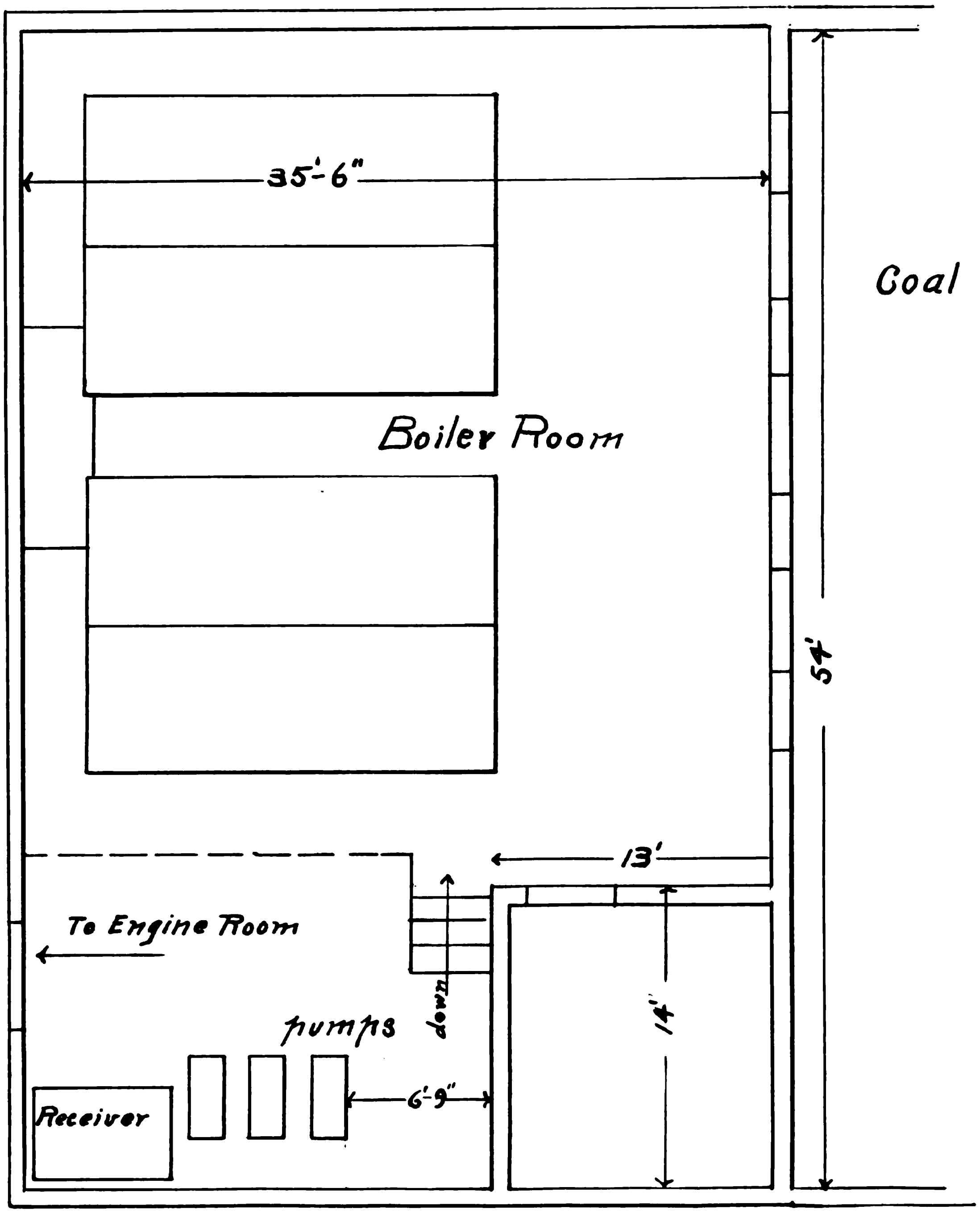

35'-6"
Coal
Boiler Room
54'
13'
To Engine Room
down
14'
pumps
Receiver
6'-9"

Fig. 1

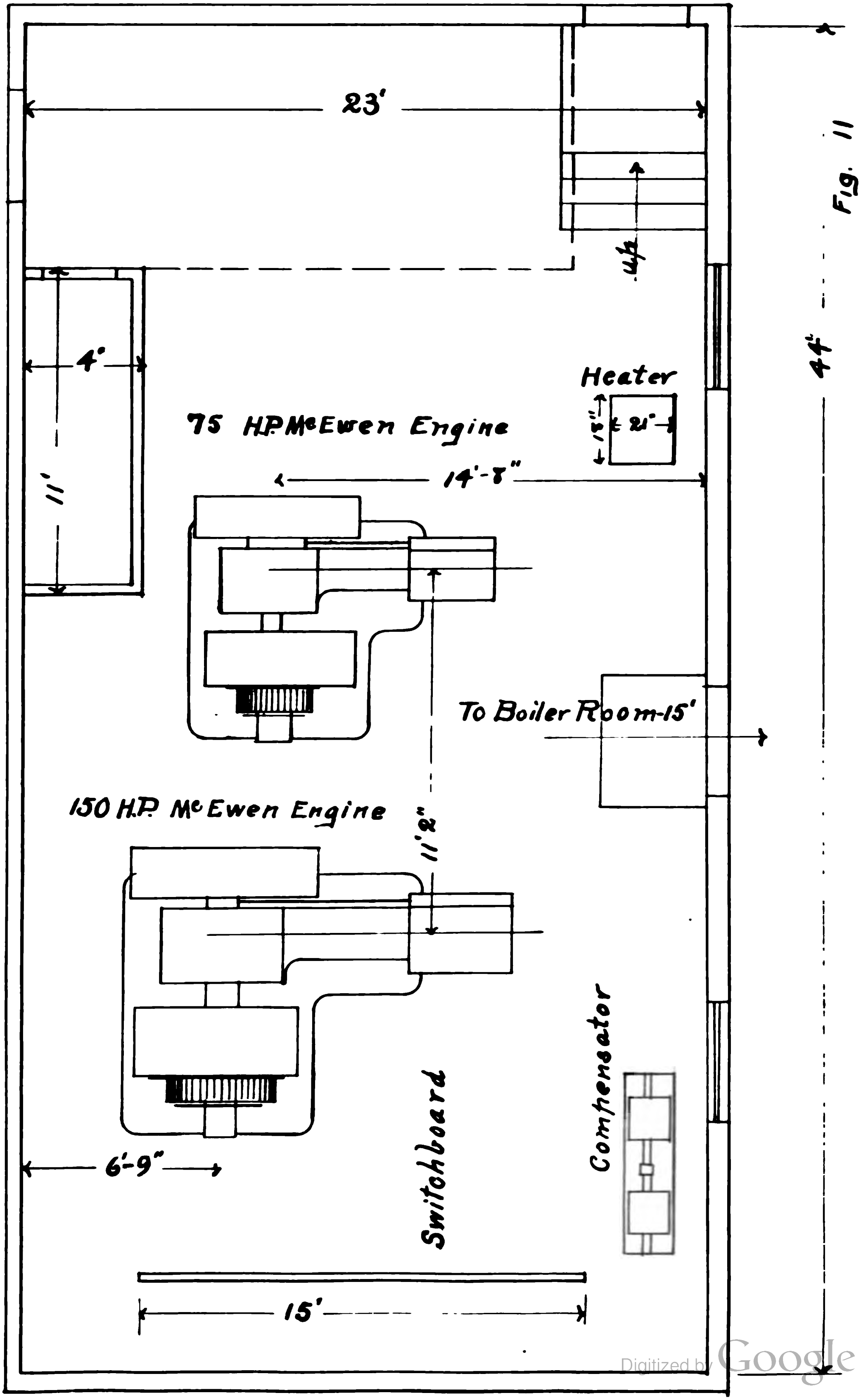
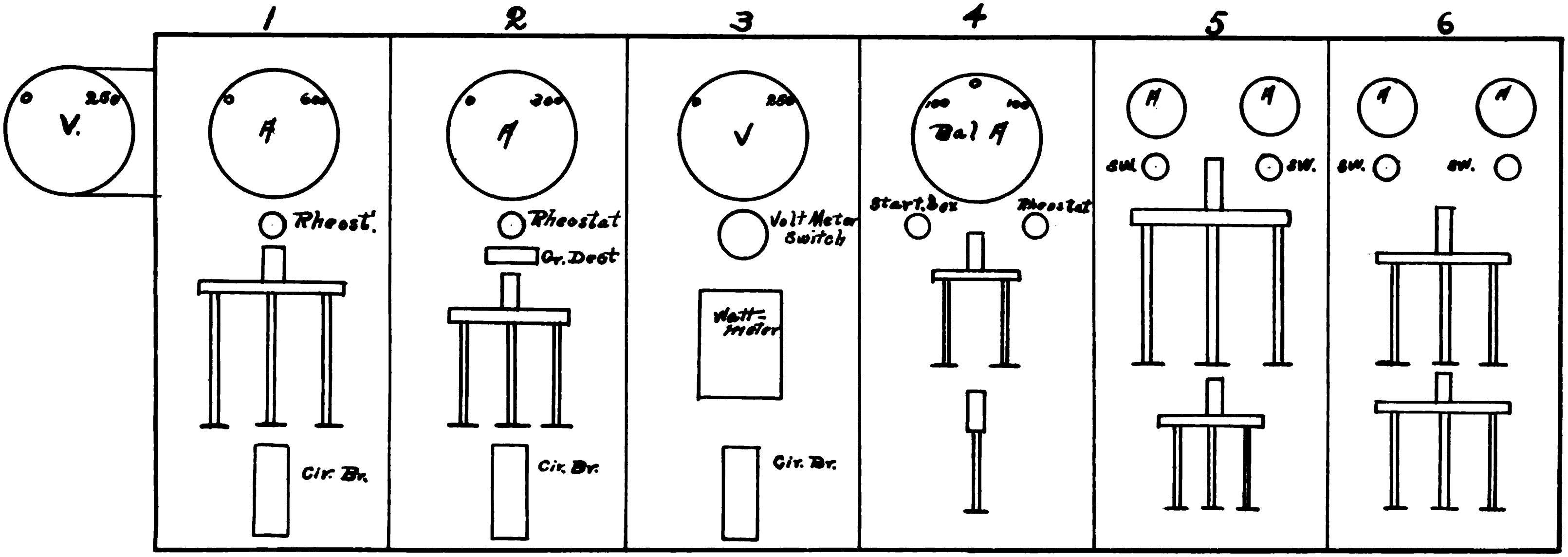
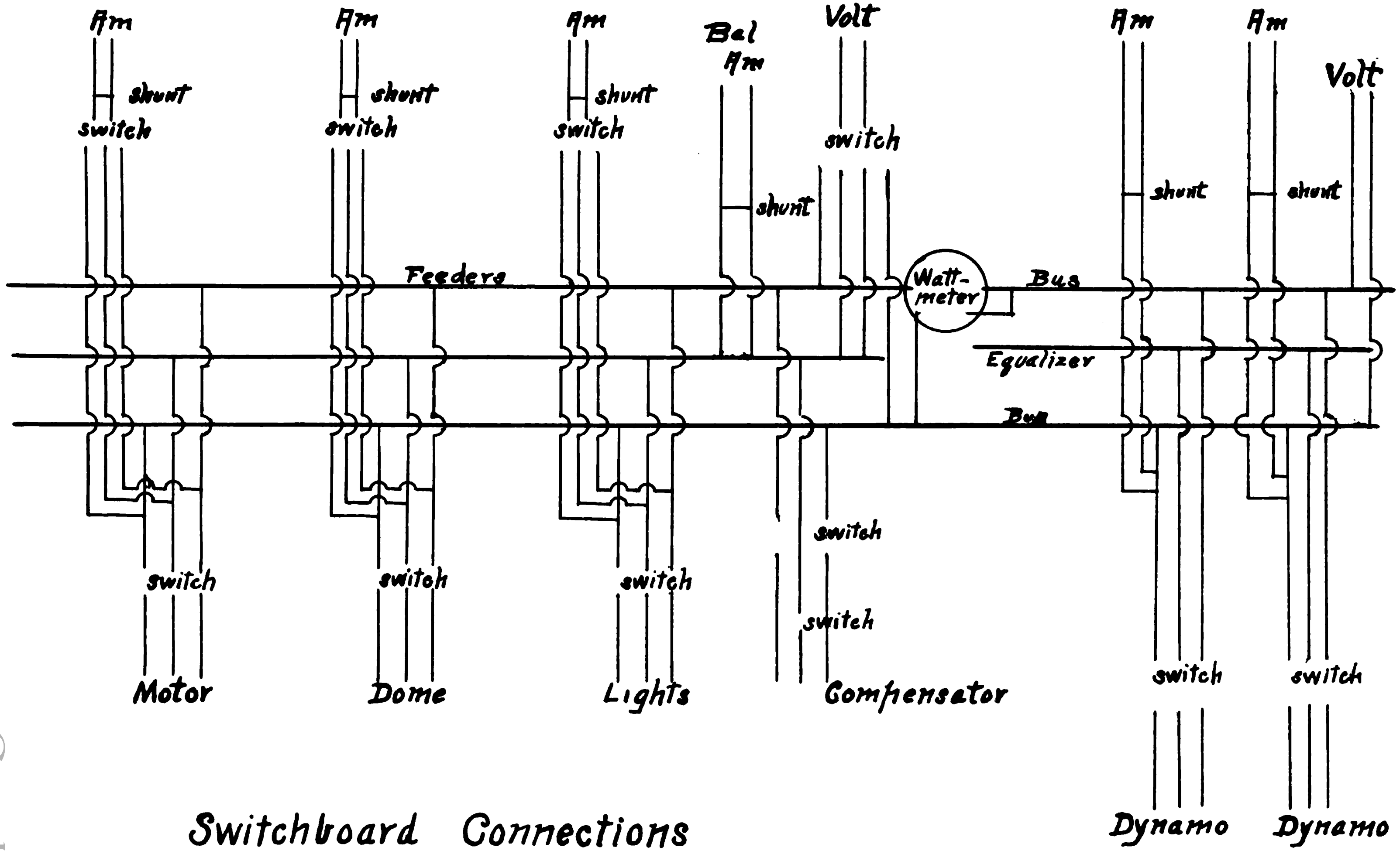

23'
up
4'
11'
Heater
15"
21"
75 H.P. McEwen Engine
14'-8"
To Boiler Room-15'
150 H.P. McEwen Engine
11'2"
44'
6'-9"
Switchboard
Compensator
15'

Fig. 11



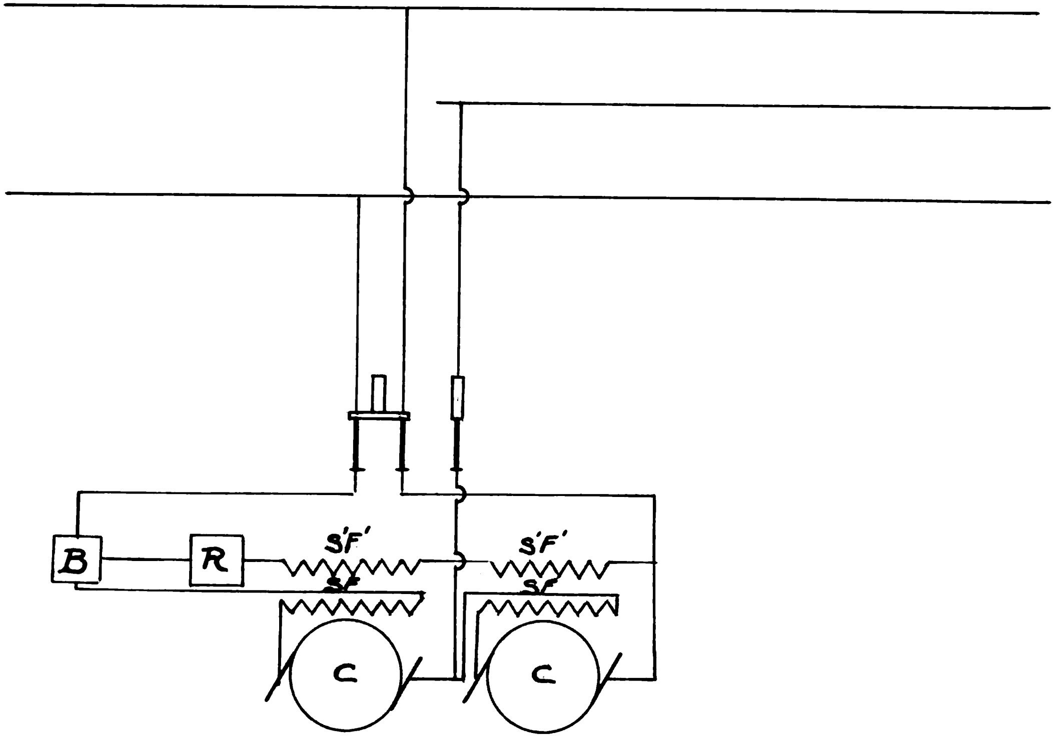
SWITCH BOARD

Fig 111



Switchboard Connections

Fig. IV



C = Compensators
B = Starting Box
R = Resistance
S'F' = Shunt Field
SF = Series "

Compensator Connections

Fig. V.

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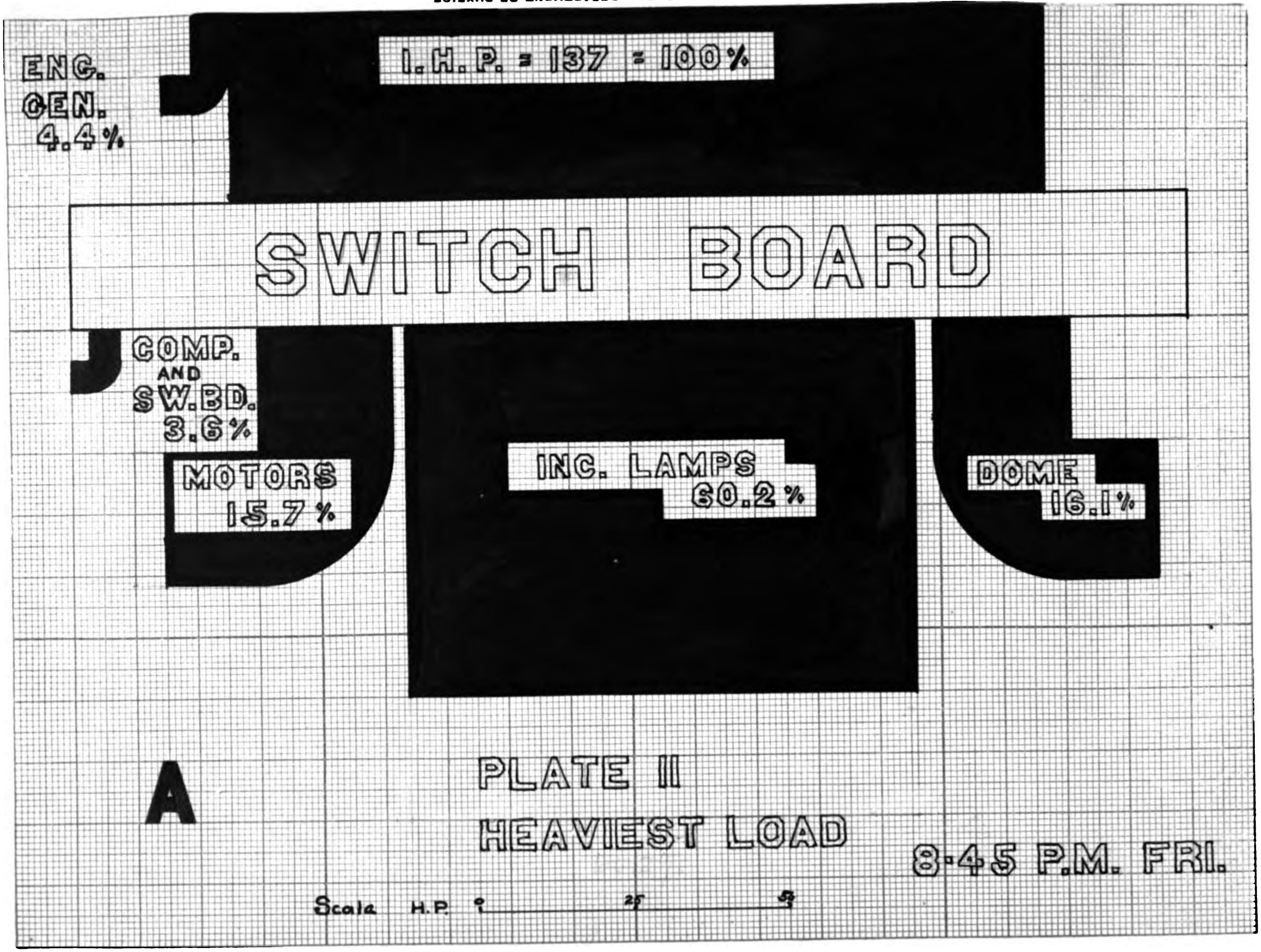

PLATE II

HEAVIEST LOAD

8·45 P.M. FRI.

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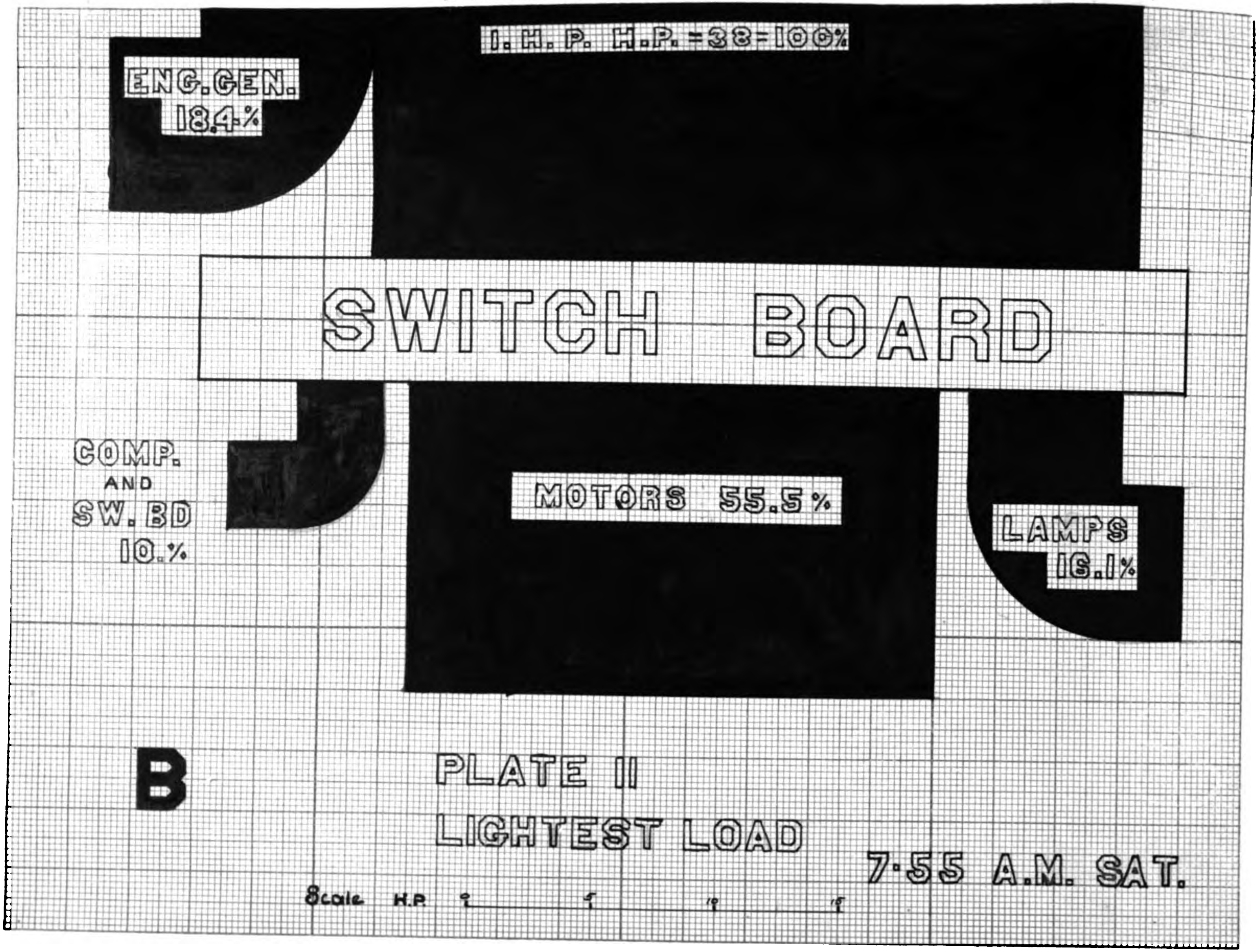

PLATE II

LIGHTEST LOAD

7·55 A.M. SAT.

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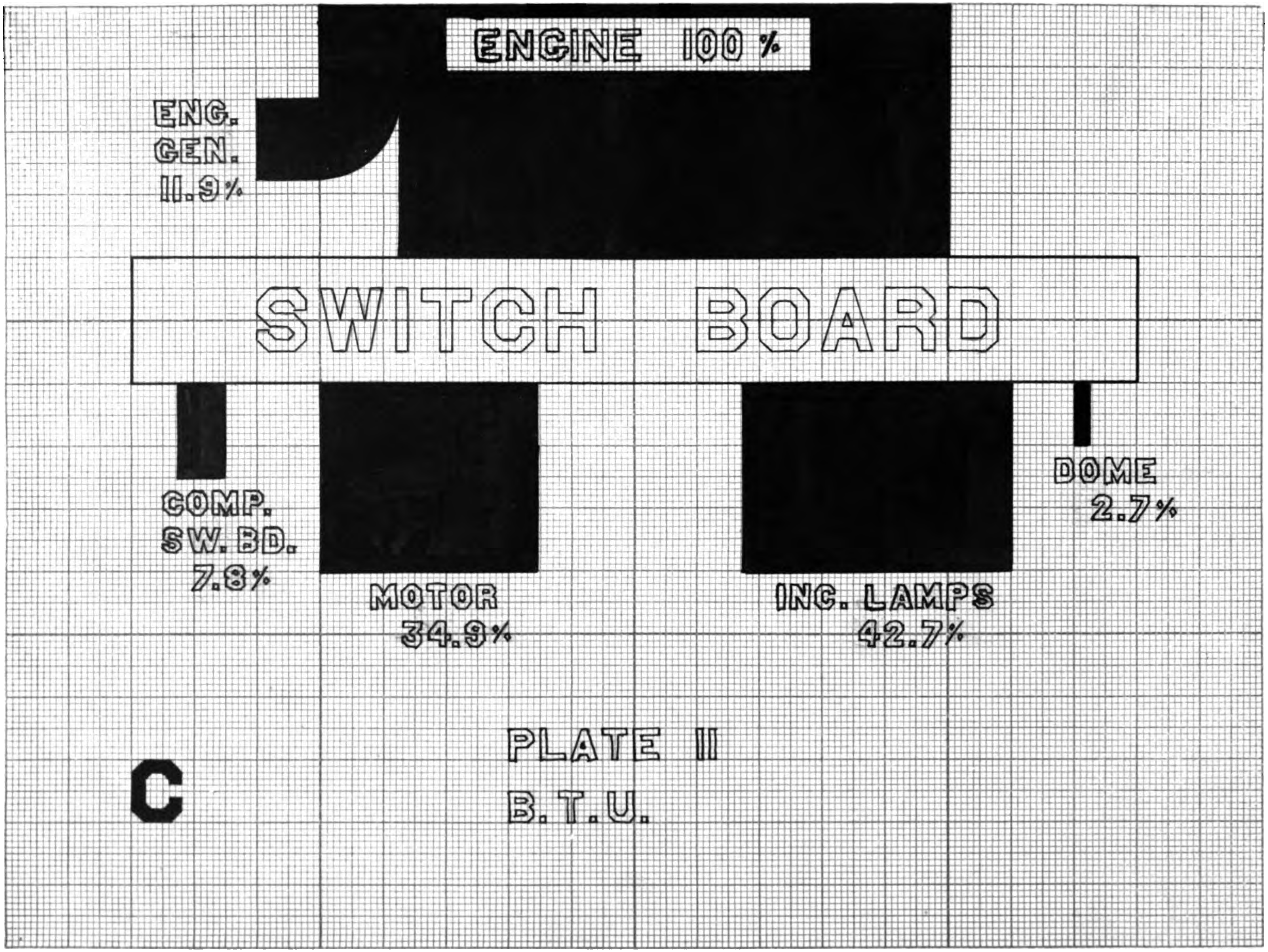


PLATE II

B.T.U.

UNIVERSITY OF WISCONSIN, DEPARTMENT OF PHYSICS.

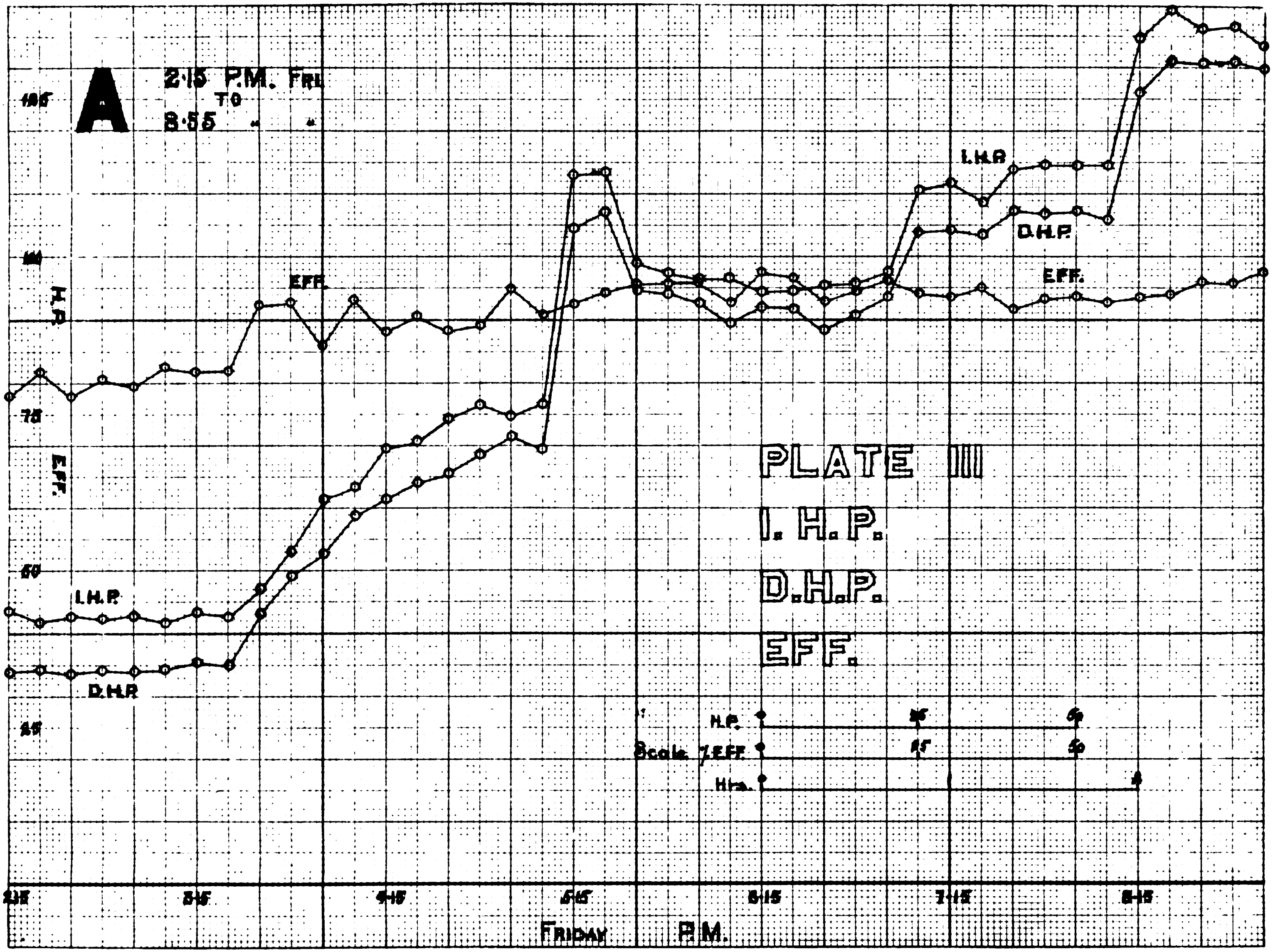
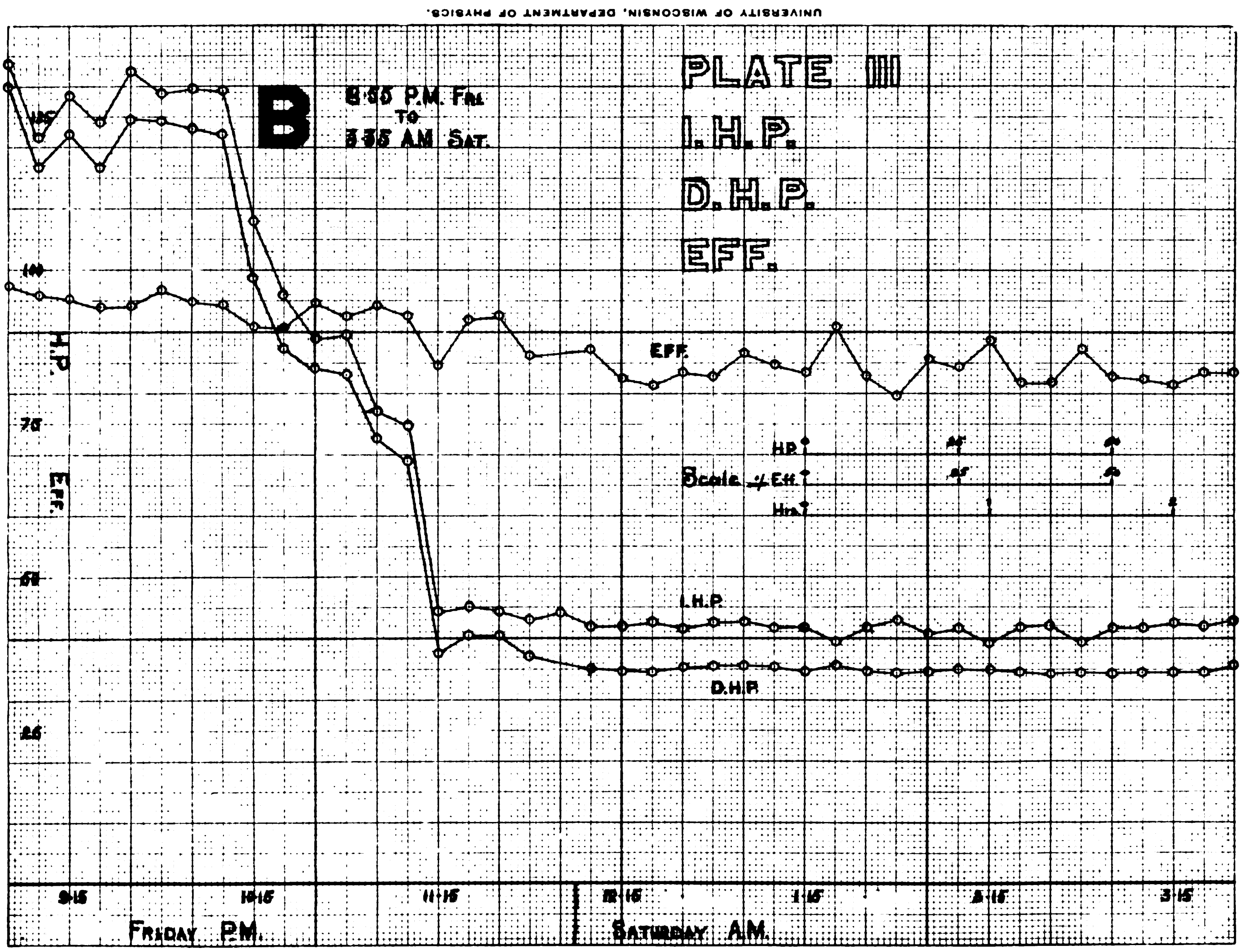


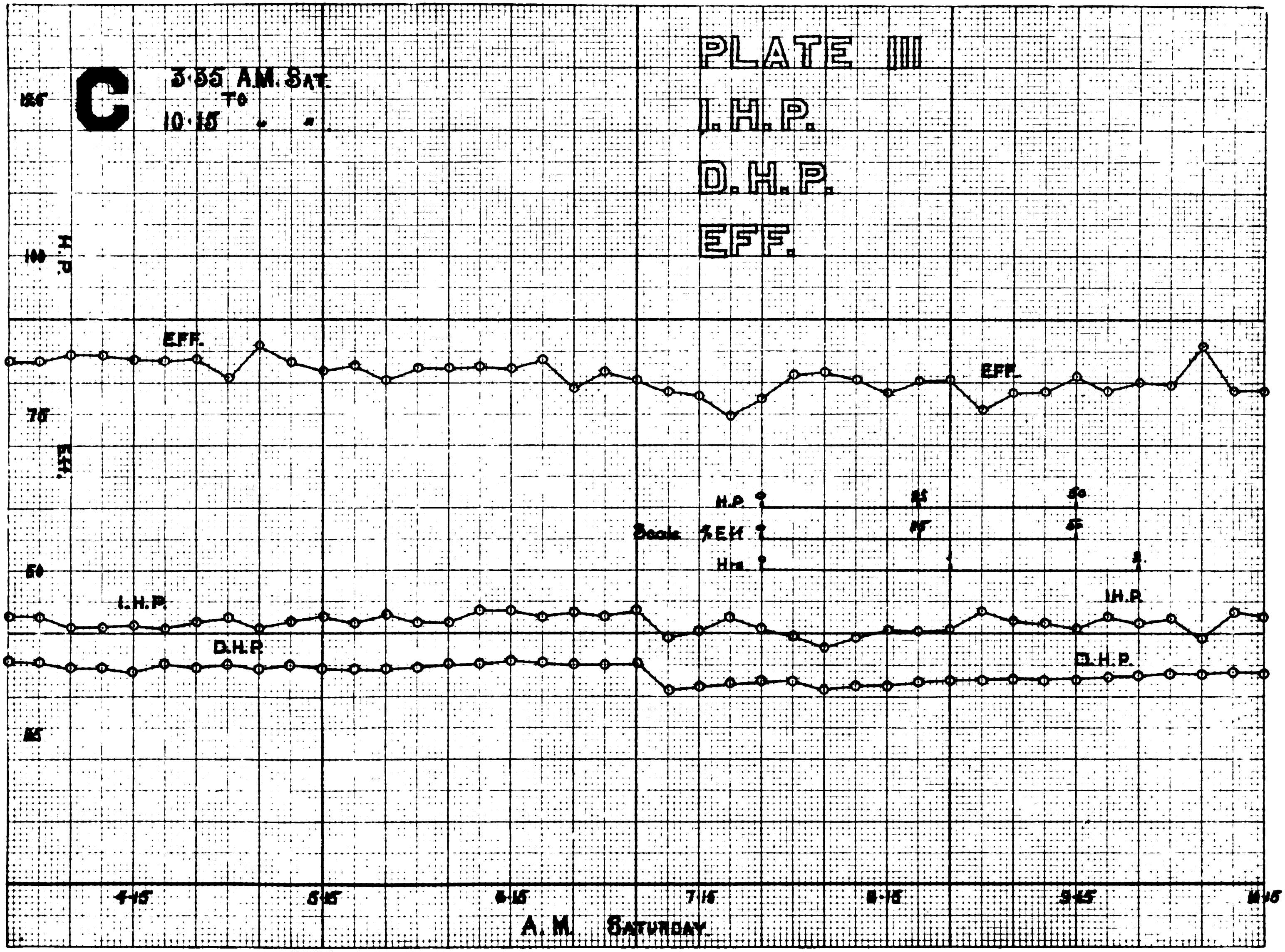
PLATE III

I. H. P.

D. H. P.

EFF.


UNIVERSITY OF WISCONSIN, DEPARTMENT OF PHYSICS.
PLATE III
I. H. P.
D. H. P.
EFF.
B
8:55 P.M. Fri
to
3:55 AM Sat.
125
100
75
50
25
H.P.
EFF.
EFF.
I.H.P.
D.H.P.
H.P.
Scale of Eff.
Hrs.
1
2
9:15
10:15
11:15
12:15
1:15
2:15
3:15
Friday P.M.
Saturday A.M.



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UNIVERSITY OF WISCONSIN, DEPARTMENT OF PHYSICS.

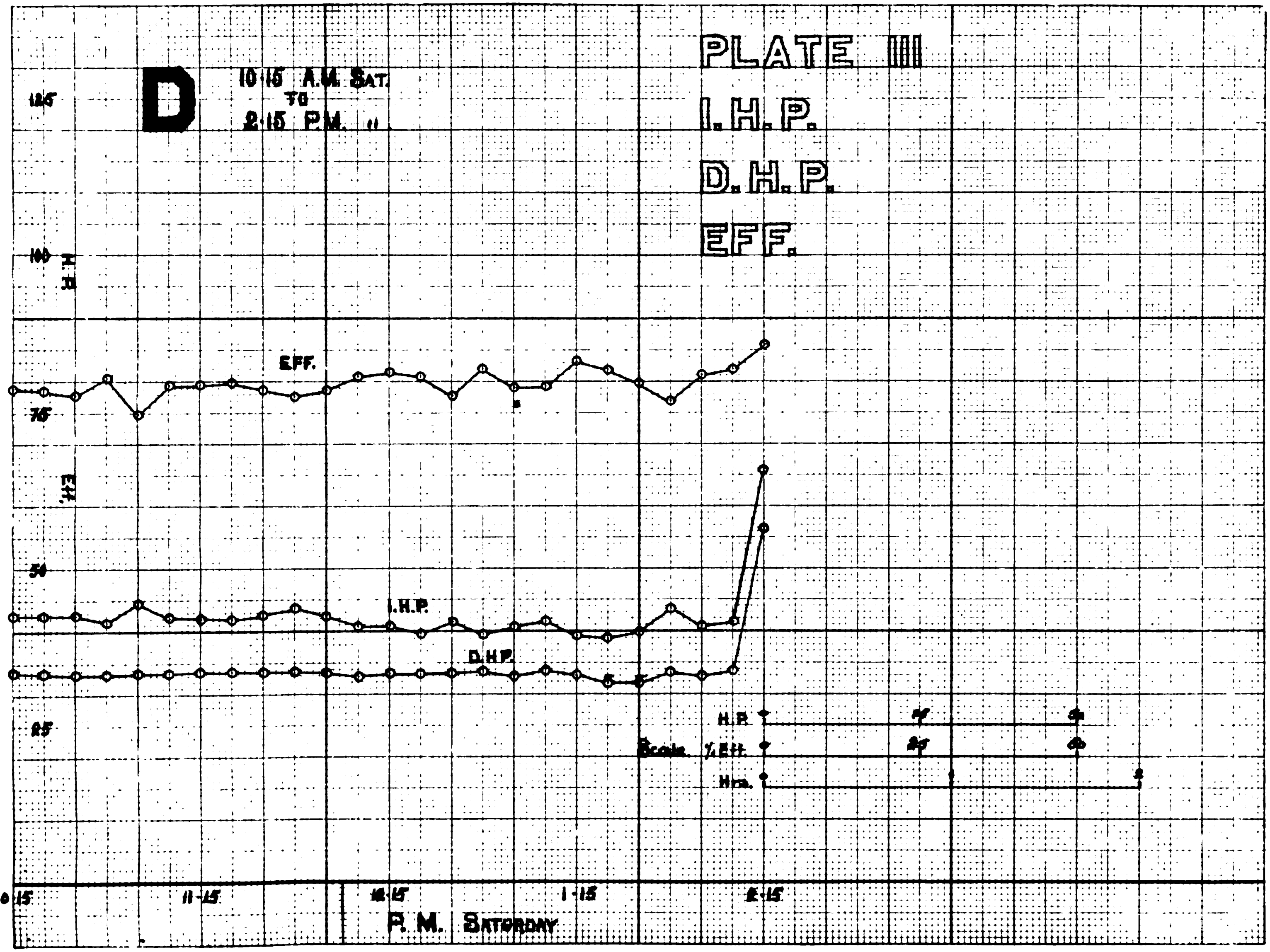
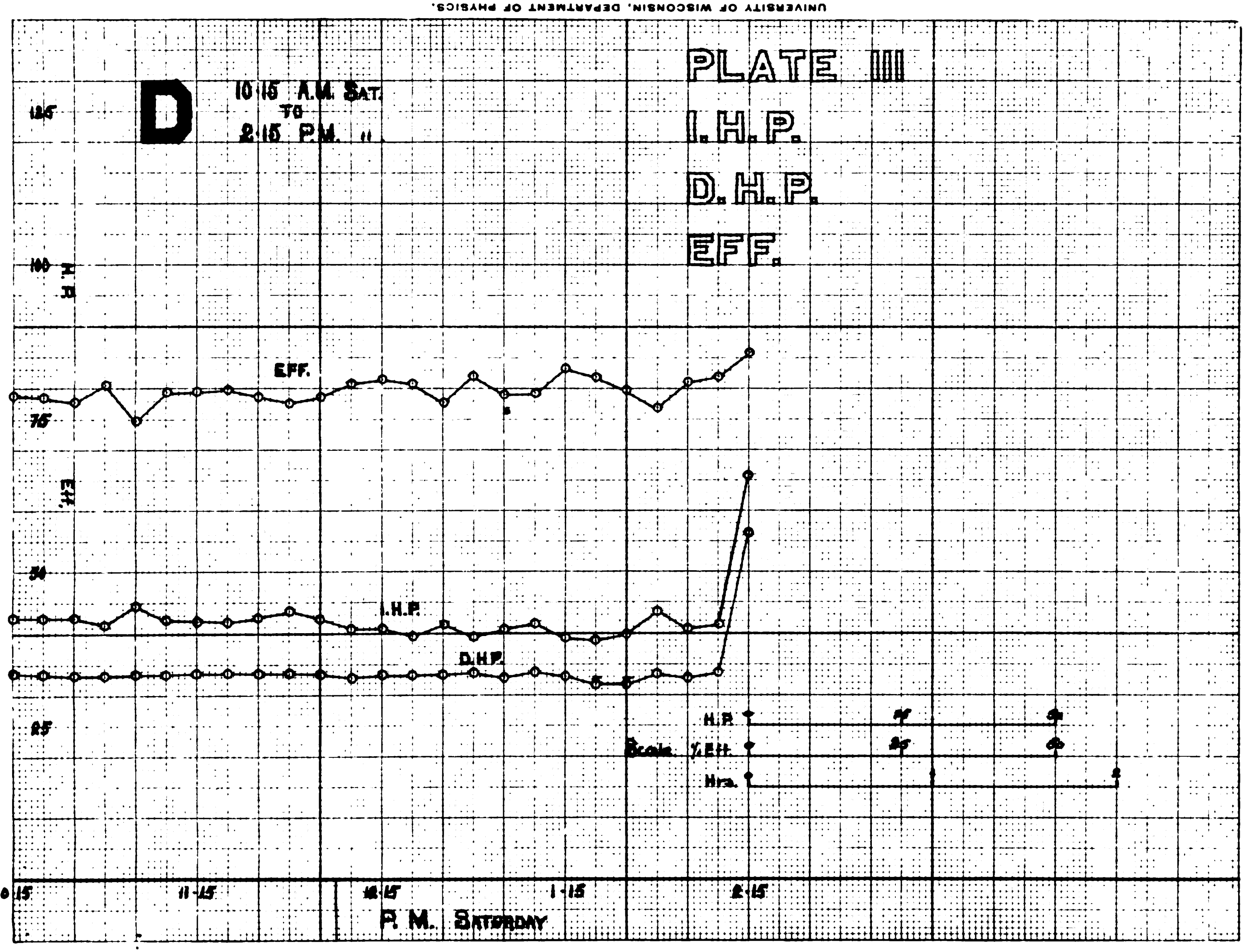


PLATE III

I. H. P.

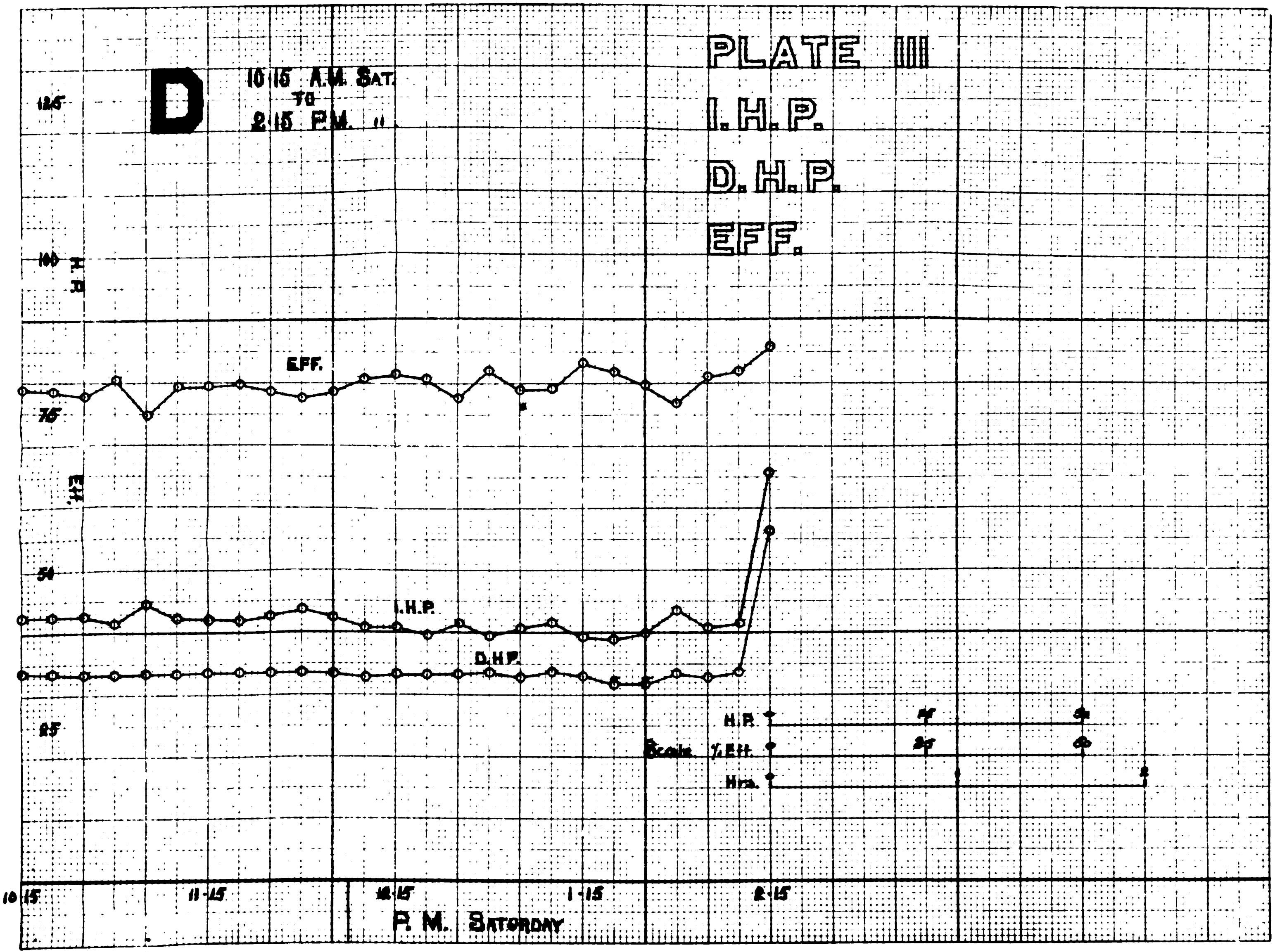
D. H. P.

EFF.


UNIVERSITY OF WISCONSIN, DEPARTMENT OF PHYSICS.
PLATE III
I. H. P.
D. H. P.
EFF.
D
10 15 A.M. Sat.
to
2 15 P.M. "
125
100
H.P.
75
Eff.
50
25
EFF.
I.H.P.
D.H.P.
Scale
H.P.
% Eff.
Hrs.
1
2
10 15
11 15
12 15
1 15
2 15
P.M. Saturday

UNIVERSITY OF WISCONSIN, DEPARTMENT OF PHYSICS.

PLATE III



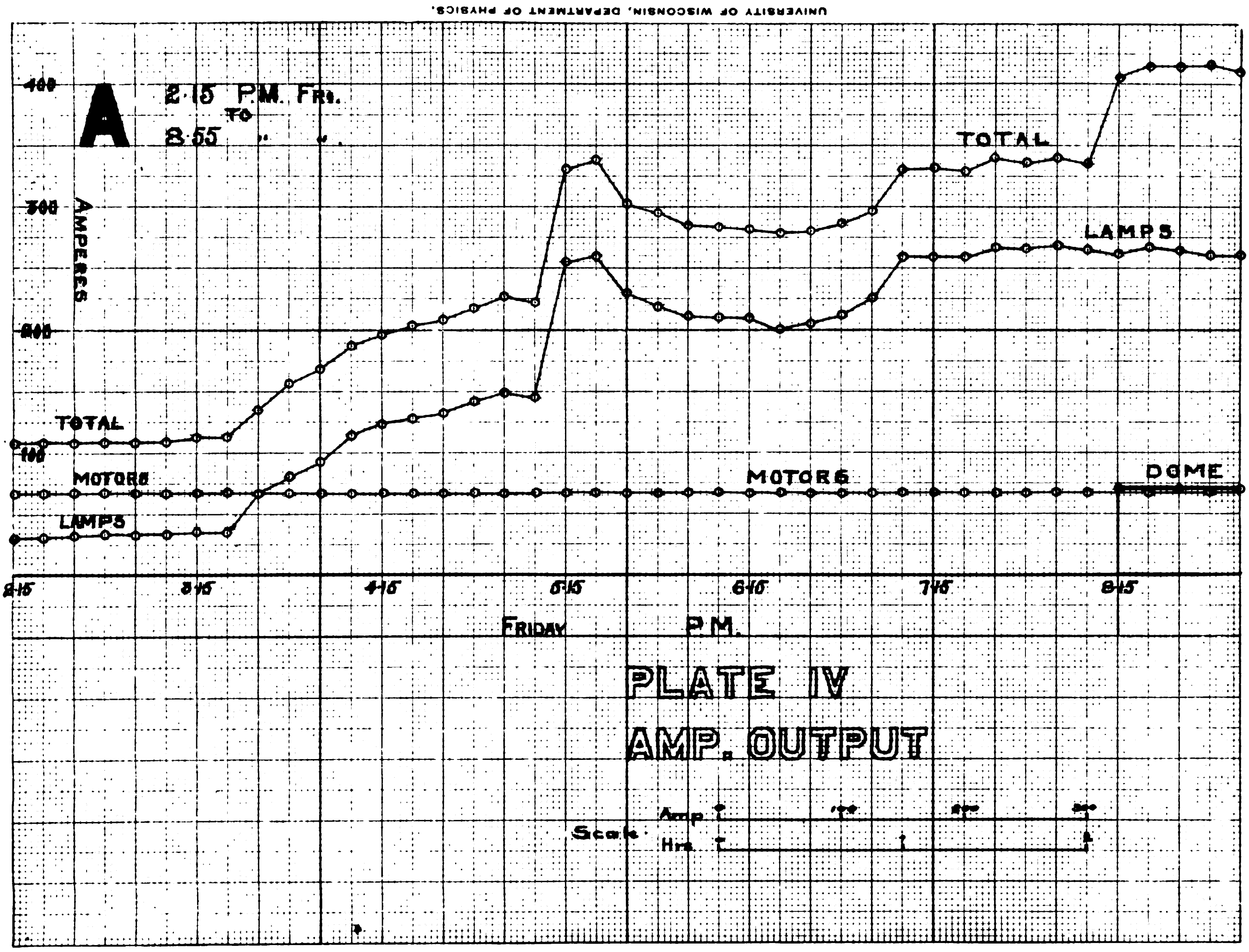
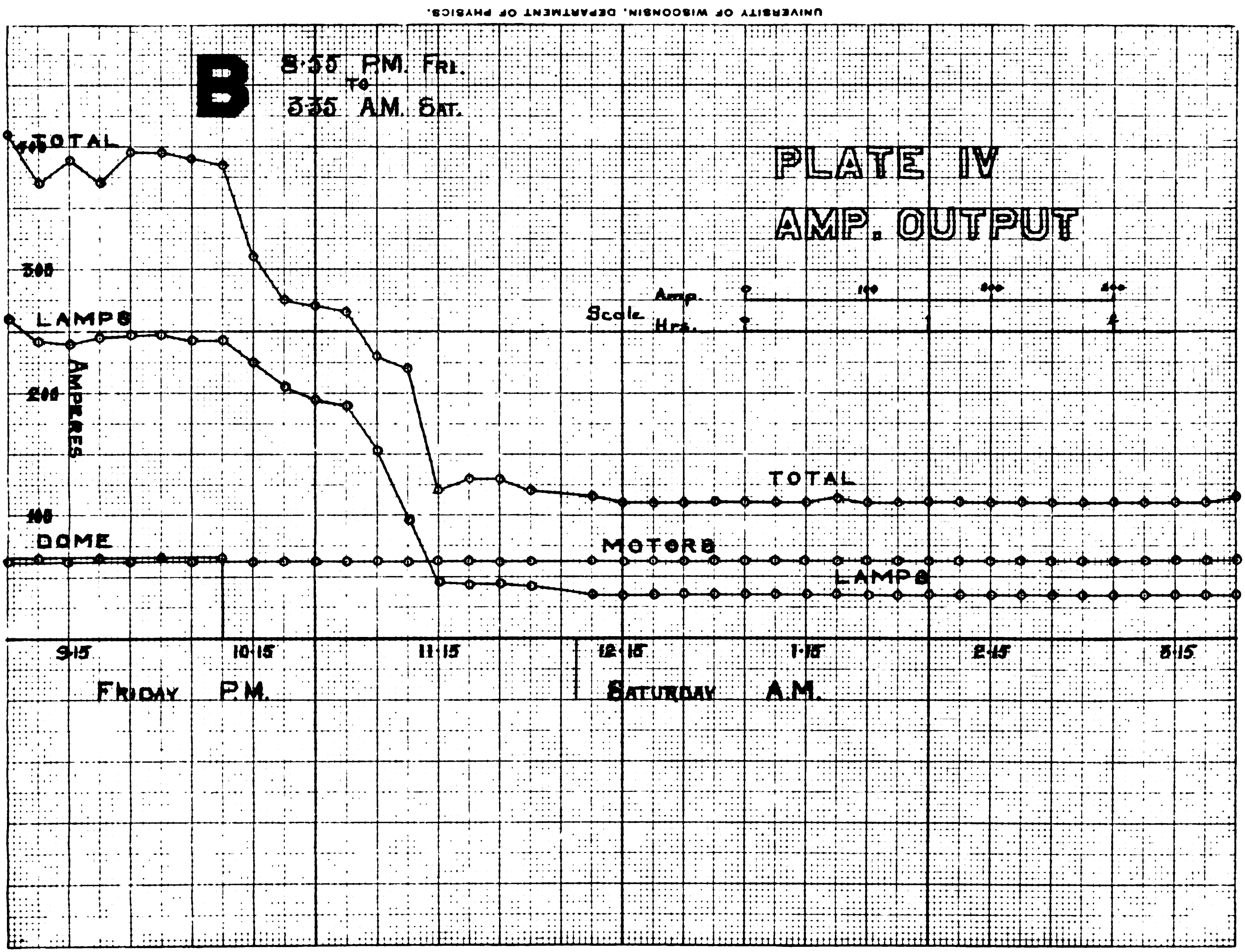
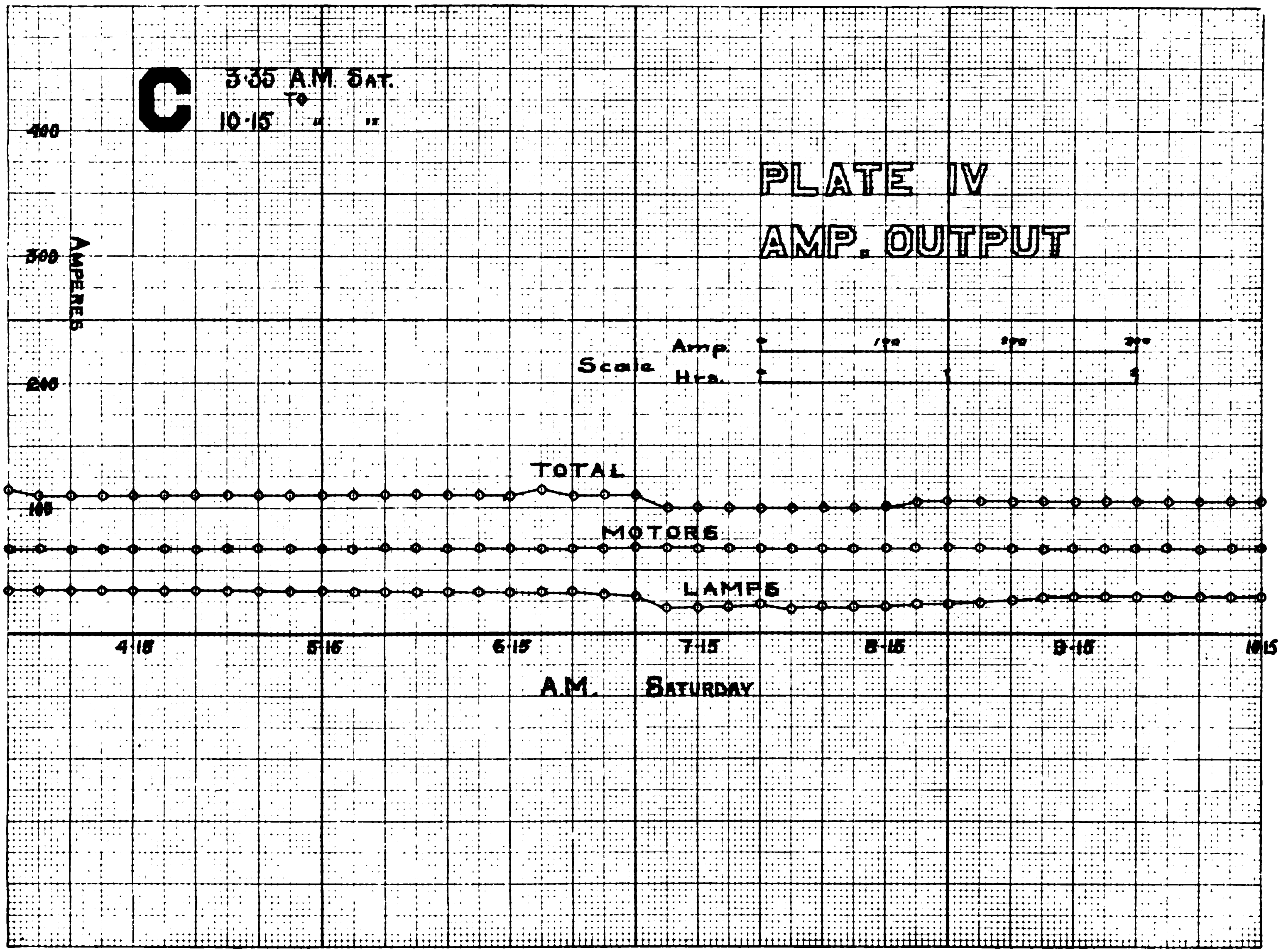


PLATE IV

AMP. OUTPUT

UNIVERSITY OF WISCONSIN, DEPARTMENT OF PHYSICS.
B
8.55 P.M. FRI.
TO
3.35 A.M. SAT.
PLATE IV
AMP. OUTPUT
Scale
Amp.
0
100
200
300
Hrs.
0
1
2
TOTAL
400
300
LAMPS
200
AMPERES
TOTAL
100
DOME
MOTORS
LAMPS
9.15
10.15
11.15
12.15
1.15
2.15
3.15
FRIDAY P.M.
SATURDAY A.M.

UNIVERSITY OF WISCONSIN, DEPARTMENT OF PHYSICS.



UNIVERSITY OF WISCONSIN, DEPARTMENT OF PHYSICS.

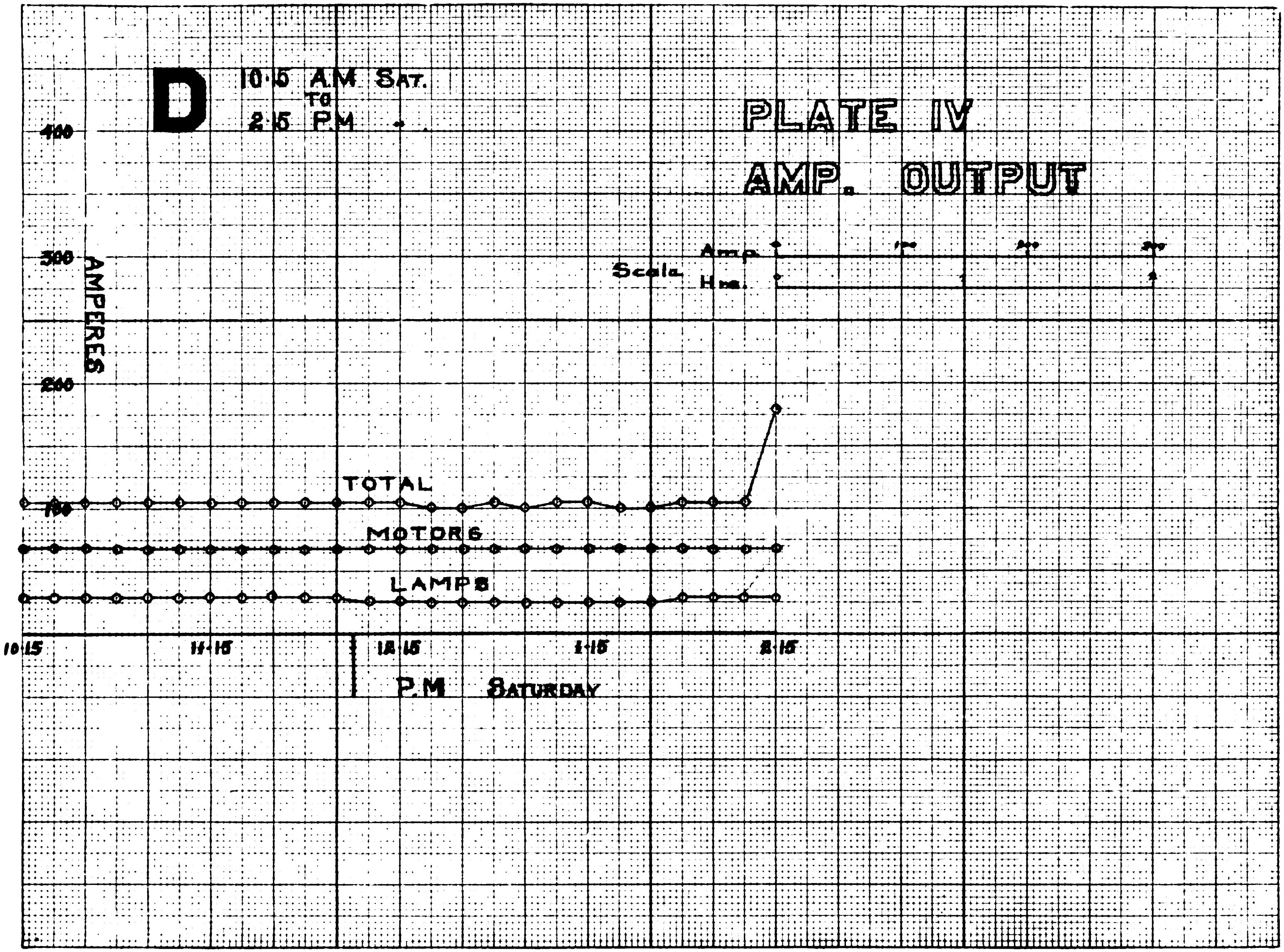
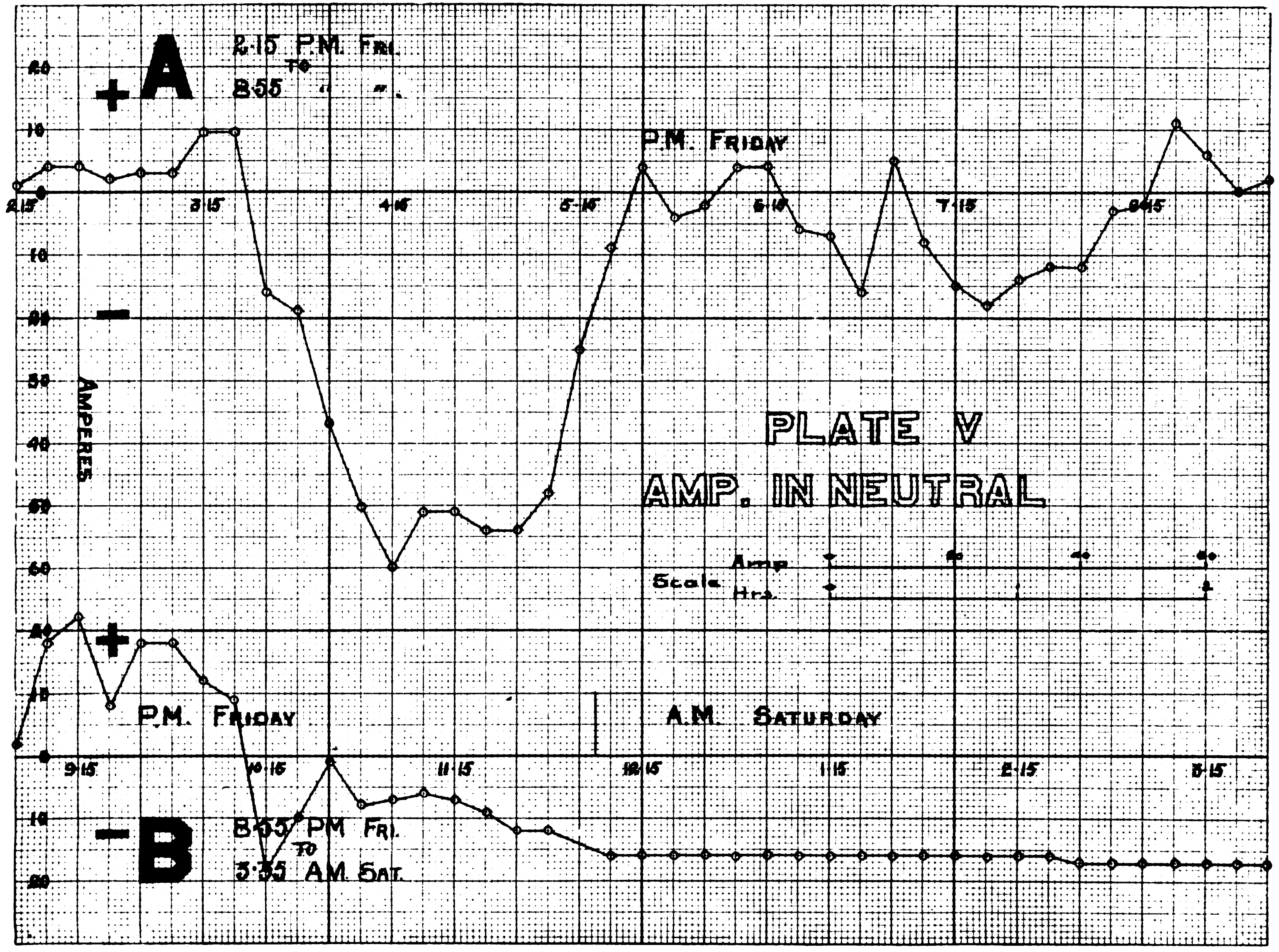


PLATE IV

AMP. OUTPUT

UNIVERSITY OF WISCONSIN, DEPARTMENT OF PHYSICS.



UNIVERSITY OF WISCONSIN. DEPARTMENT OF PHYSICS.

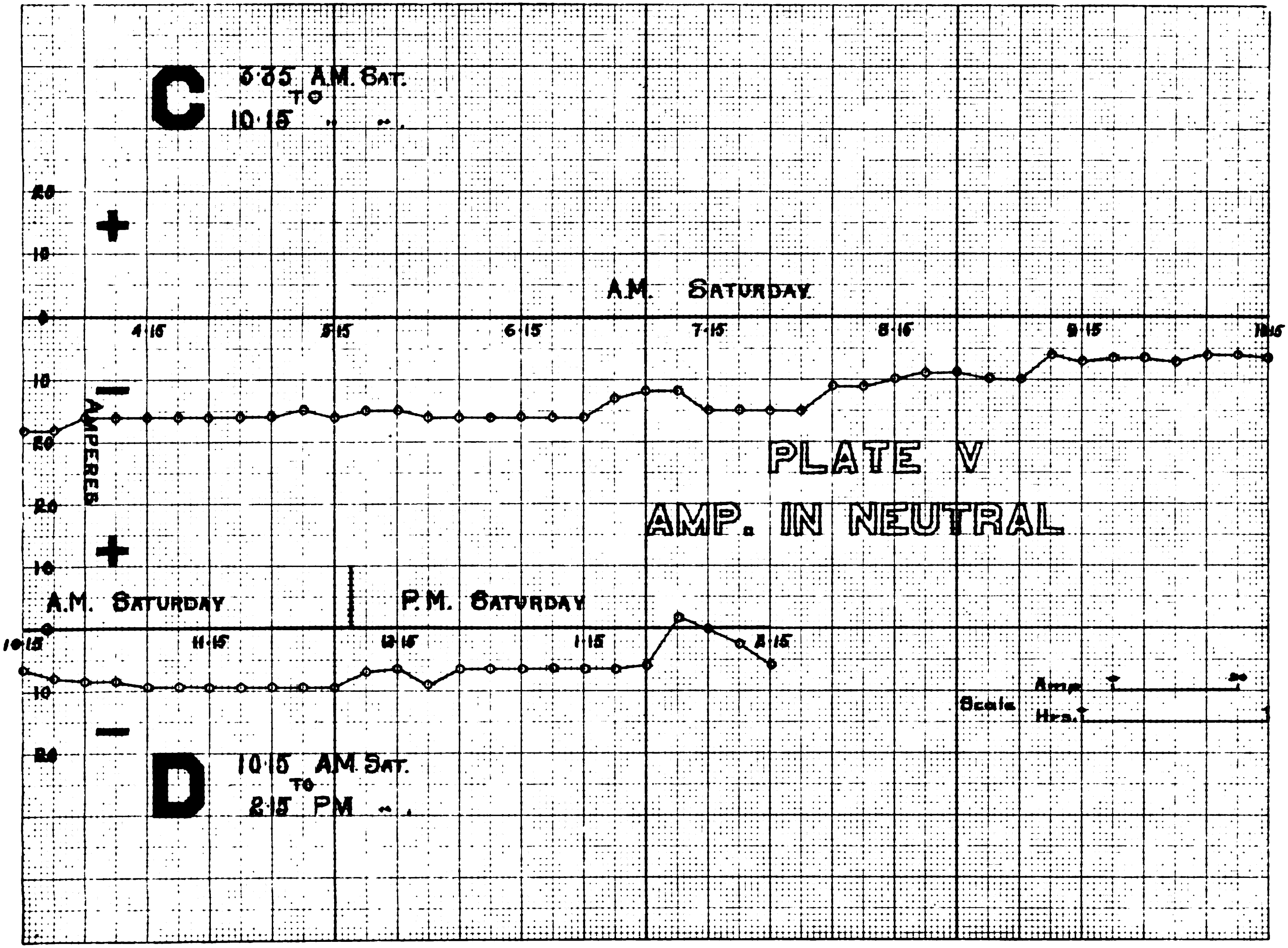


PLATE V

AMP. IN NEUTRAL

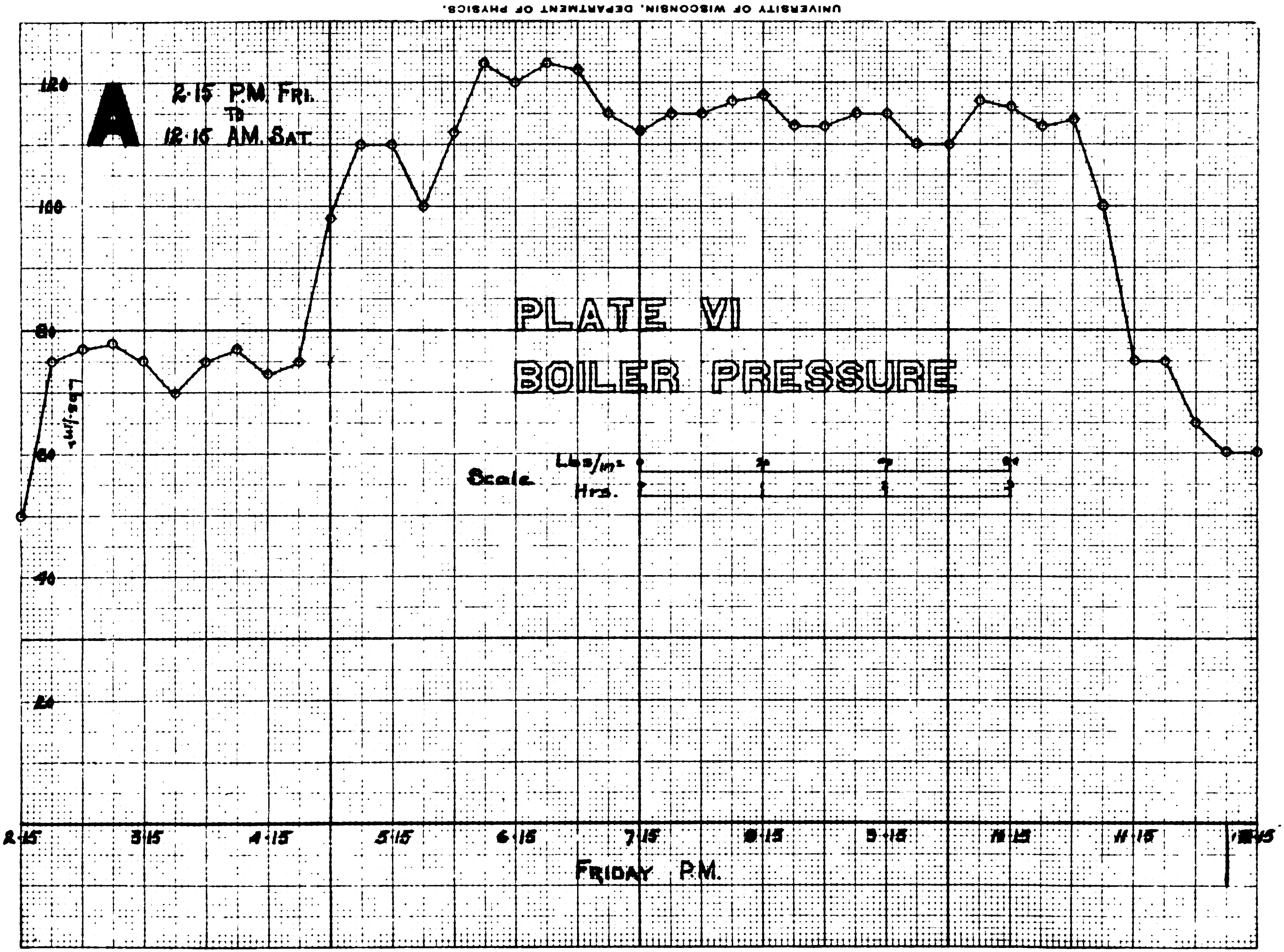


PLATE VI
BOILER PRESSURE

UNIVERSITY OF WISCONSIN, DEPARTMENT OF PHYSICS.

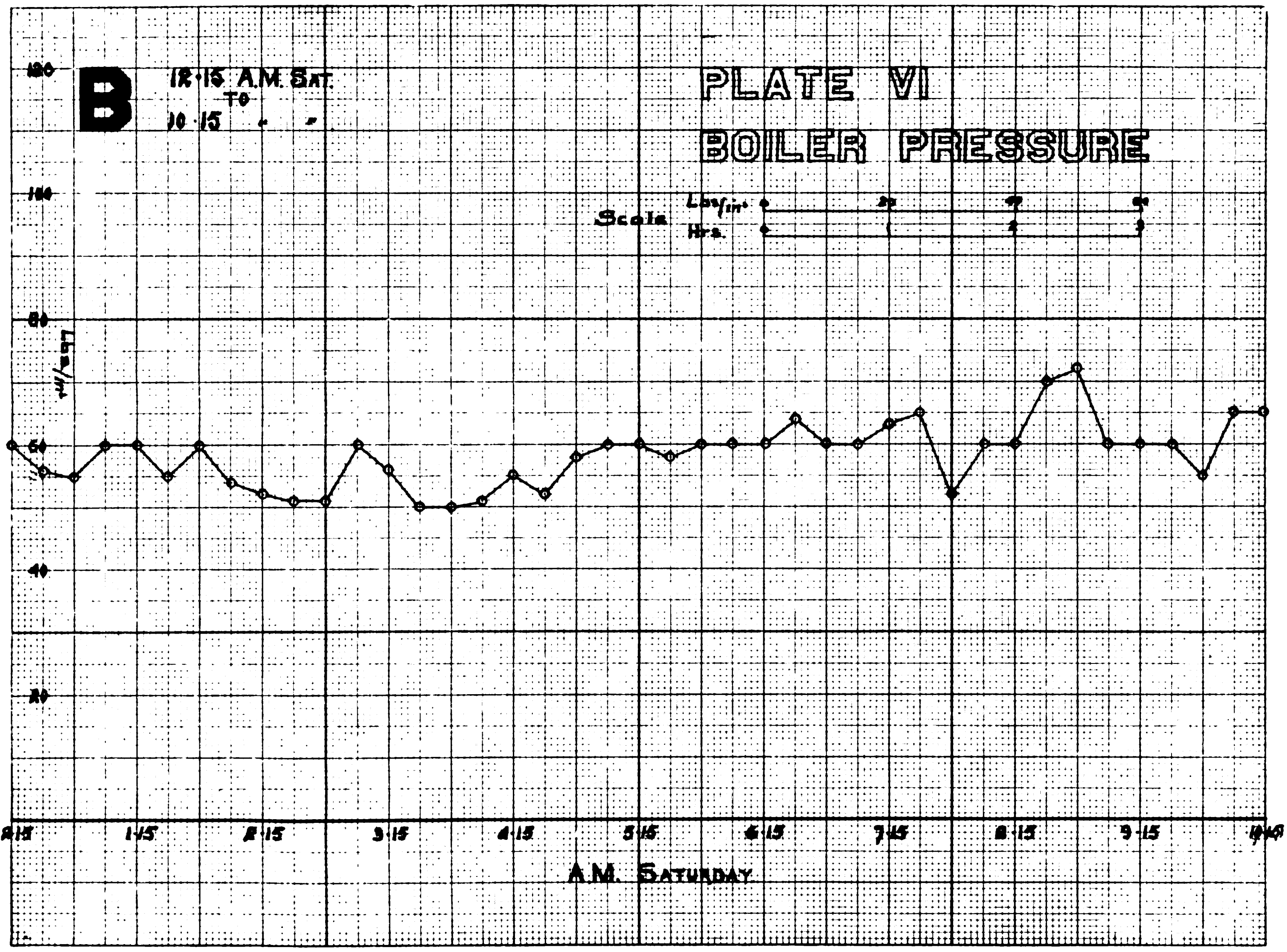


PLATE VI
BOILER PRESSURE

UNIVERSITY OF WISCONSIN, DEPARTMENT OF PHYSICS.

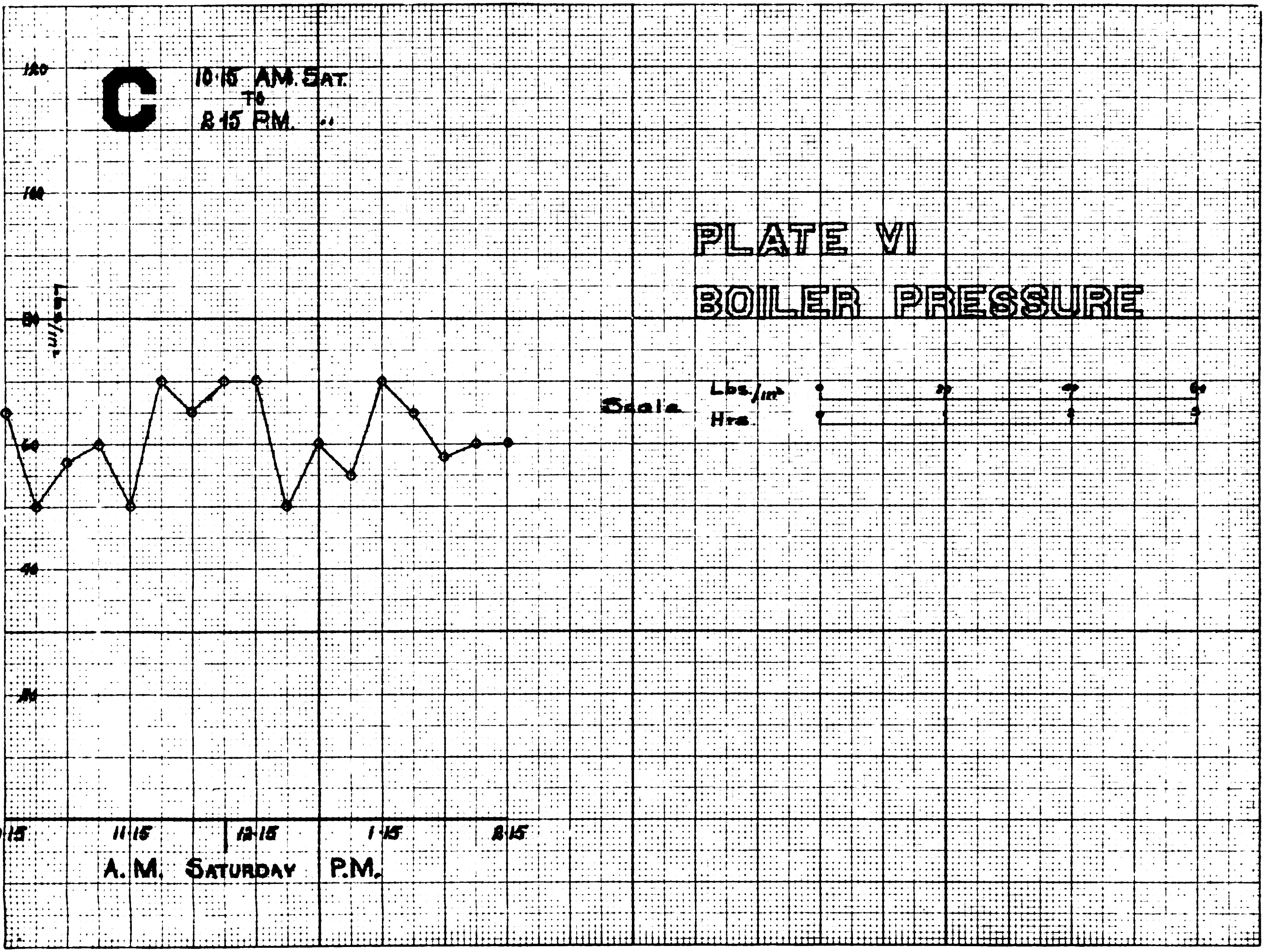
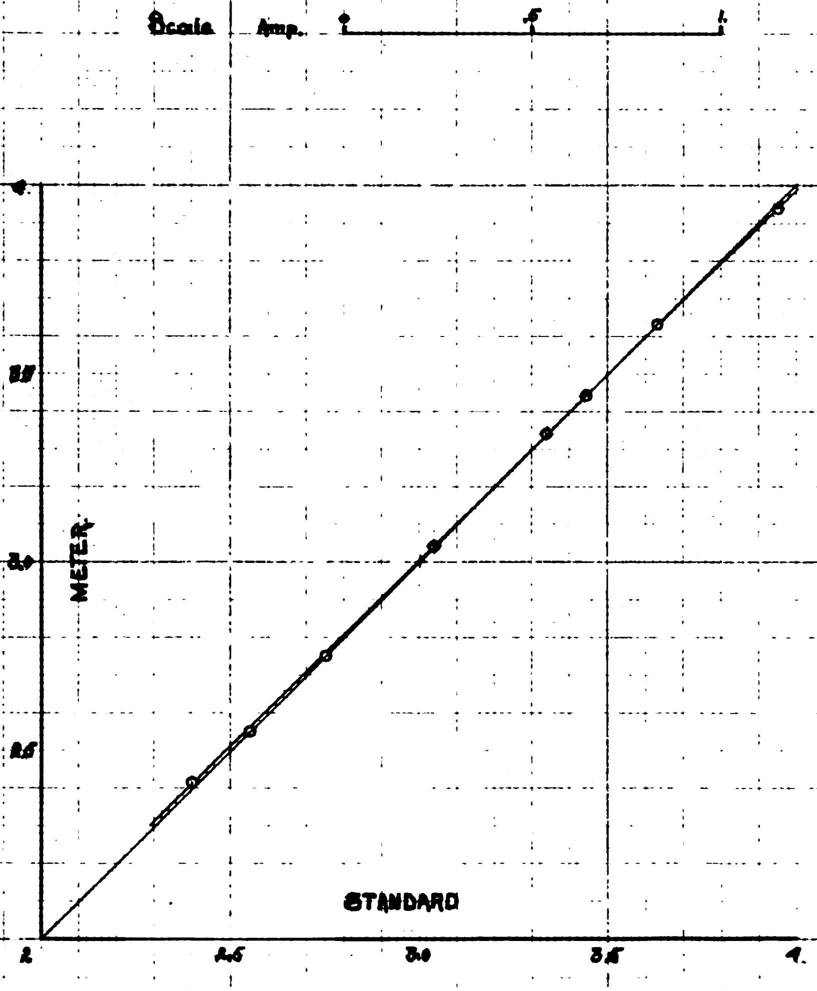


PLATE VI

BOILER PRESSURE

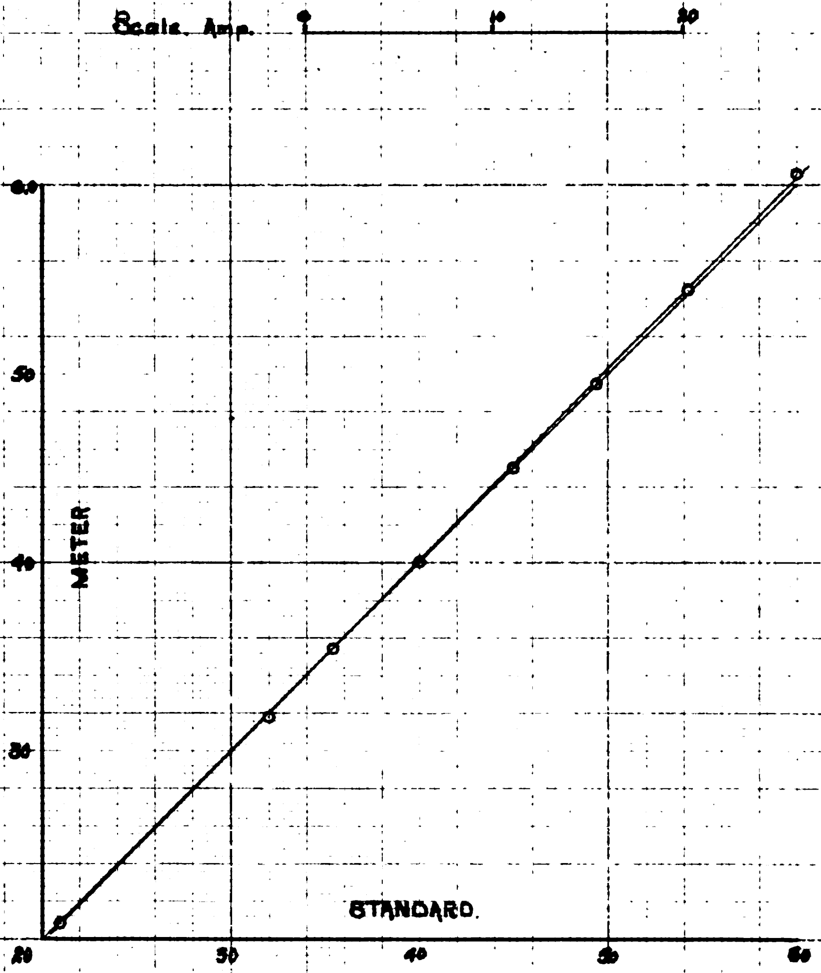
PLATE VII



CALIBRATION
OF
WESTON A.M. NO. 5750

UNIVERSITY OF WISCONSIN DEPARTMENT OF PHYSICS

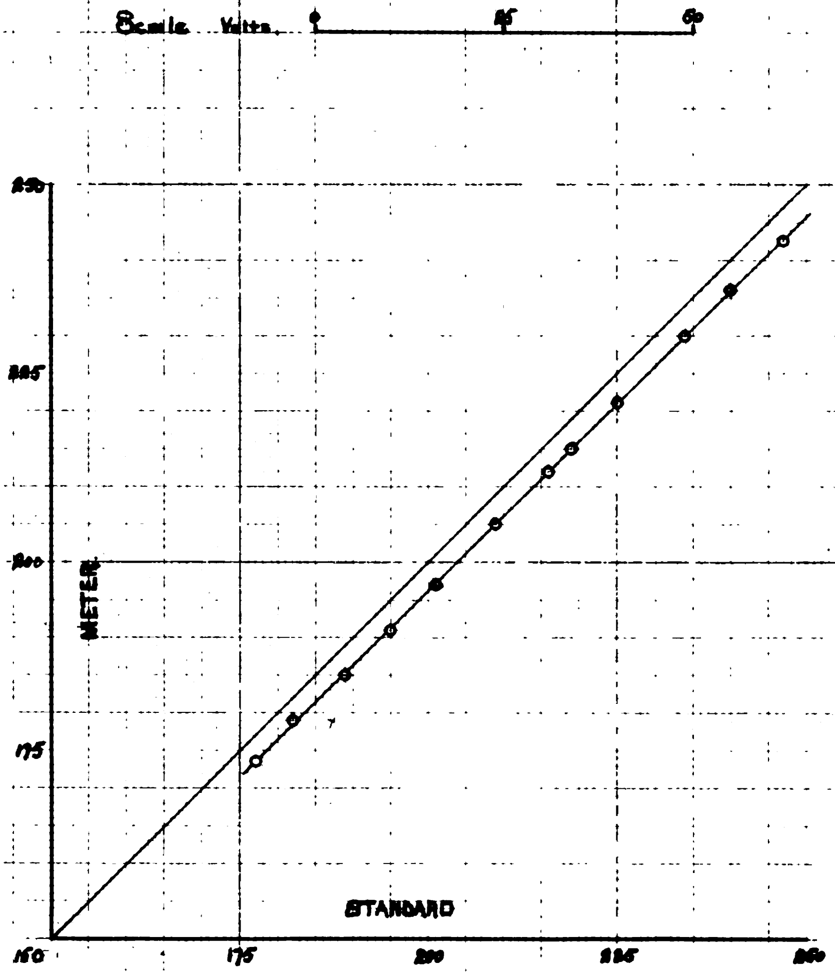
PLATE VIII



CALIBRATION OF WESTON A.M. NO. 6258

UNIVERSITY OF WISCONSIN, DEPARTMENT OF PHYSICS

PLATE IX



CALIBRATION OF WESTON V.M. NO.4450

UNIVERSITY OF WISCONSIN, DEPARTMENT OF PHYSICS

For, J. W. Belling, J. E. Brobst, and F. G. Willson.

Approved By....B. V. Swenson....

....Asst. Professor of Electrical Eng.

Date....June 13, 1903.

For, H. P. Howland.

Approved By....Storm Bull....

....Professor of Steam Engineering

Date....June 13th 1903.

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